AVIATOR'S ELEMENTARY HANDBOOK

A PRIMER OF AVIATION AND AËROPLANE MACHINES

WORKS BY THE SAME AUTHOR

Essai d'Aérodynamique du Plan. (Hachette et Cie. Paris 1911.)

Essai d'Aérodynamique, 2e série. (Hachette 1912.)

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Essai d'Aérodynamique, 4e série, surfaces courbes. (Gauthier-Villars, Paris 1914.)

Exposé Élémentaire des Connaissances générales utiles aux Aviateurs.[1] (Lahure, Paris 1917.)

The Aviator's Pocket Dictionary and Table-book. (Brentano's, New York.) $1.00 net.

[1] The present translation is a revised and enlarged edition of this book.

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A PRIMER OF AVIATION AND
AËROPLANE MACHINES

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INTRODUCTION

An airplane consists of a sustainer, or cell, and a power group.

The cell is composed of two sets of organs: On the one hand, the *wings* which support the whole; the *wing flaps*, which maintain the lateral equilibrium; the *rudder* and *elevator*, which make steering possible. On the other hand, the *body*, or "fuselage," in which the pilot and passenger take their places, and where the fuel tanks and instruments are located; the *landing gear*, consisting of wheels, flexibly attached to the airplane.

The first perform an active part in the running of the machine and, for this reason, are called "active elements."

The second, though essential, are inactive and are commonly spoken of as "passive elements."

The power group includes the *engine* and *propeller*. The engine is the source of energy, which produces the rotary motion of the special organ, called the propeller, which in turn transforms this rotary motion into the forward motion of the airplane.

These various organs are found on all airplanes, differing only in number and arrangement. The present airplanes have either one, two, or three pairs of wings and one or more engines and propellers.

How is the airplane sustained in the air? The pull or push, exerted by the propeller, communicates to the cell a certain speed, thereby engendering an upward lift, which counteracts the weight of the machine.

Such is the subject-matter of the following pages. It is my purpose to give in as simple language as possible, without mathematical formulas, the elementary information indispensable to a student-pilot.

If some rather abstract theories of air dynamics (see Vocabulary, page 113) are introduced, it is because I know of no better way to explain the mechanism and functions of the wings and rudders.

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Aviator's Elementary Handbook

CHAPTER I

THE SUSTAINER

IT is known that the air about us has weight. The pressure exerted by the atmosphere upon each square centimeter of any surface at sea level is about 1033 grams, which is equal to the pressure of a column of water 1033 centimeters (nearly 34 feet) high. This pressure, being due to the weight of the air above, diminishes with the altitude. Since it is exerted equally on all sides of the stationary objects about us, it has no apparent effect upon them. But, if one of these bodies is moved through the air, the equilibrium is disturbed, compressing the air in front of the body and expanding it in the rear. We say that the points of the surface in contact with the compressed air are

under *pressure*, and that the points in contact with the expanded air are under diminished pressure or *suction*. We will measure these increased and diminished pressures in weight units or height of water column, 1 gram being the weight of a column of water 1 centimeter square and 1 centimeter high.

The greatest amount of suction obtained on the airplane wings is from 40 or 50 grams per square

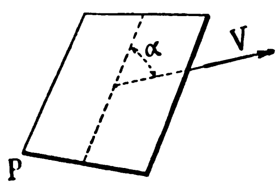

FIG. 1. Angle of Attack of Plane

centimeter, or even more, but still much less than the 1033 grams, which would be the effect of a perfect vacuum.

With these facts in mind, let us consider the simplest case, that of a small plane in motion.

We will confine ourselves to the consideration of a rectangular plane, with its longest dimension perpendicular to the course followed, or, if preferred, to the *speed*, which can also indicate the direction.

The *angle* of *attack*, or *incidence*, of a plane P, moving in calm air, is the angle α which this plane makes, at a given instant, with the *direction followed*, as determined by the motion of some particular point in this plane. This is also the direction of the velocity V (Fig. 1). This angle must not be confused with the inclination of the plane P to the *horizontal*.

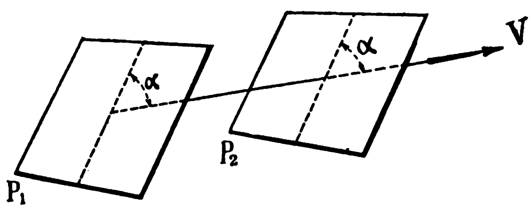

FIG. 2. Moving Plane, with Constant Angle of Attack

If the plane moves (keeping parallel to itself) from P_1 to P_2, other things being equal, its attacking angle is constant (Fig. 2). This is what we shall assume in all that follows.

We shall consider the two faces of the plane in order: the front or lower face; the rear or upper face.

Distribution of Pressures. — The distribution of the pressures on the two faces of the plane depends upon three variables.

1. The dimensions of the surface, that is, its length or *span*, and its width or *depth*.

2. The angle of attack or *incidence.*
3. The velocity or *speed.*

We shall first consider the last two as fixed, while taking the particular case of a plane moving in still air at a uniform speed of 10 meters (33 feet) per second with an attacking angle of 8°, for example. (The angles from 0° to 20° are the only angles of any practical value in aviation.)

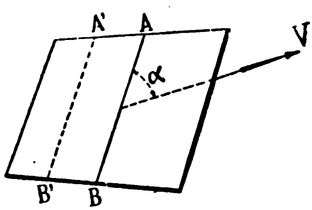

FIG. 3. Distribution of Pressure along the Lines of Greatest Inclination of a Plane

In a general way the pressure, to which the plane is subjected by the air, is greater than the barometric pressure on the front or lower face, and smaller on the rear or upper face.

The pressures of a fluid being reduced to a single force, normal (at right angles) to the given surface, all the forces engendered by these pressures have a common direction, which is perpendicular to the plane. This is also the direction of the resultant.

But, if each face is considered separately, it is seen that the action of the air, far from exerting a

uniform force on all points of the given surface, varies from one point to another. The study of these variations has enabled us to determine the air dynamics of the plane, in regard to which we must say a few words.

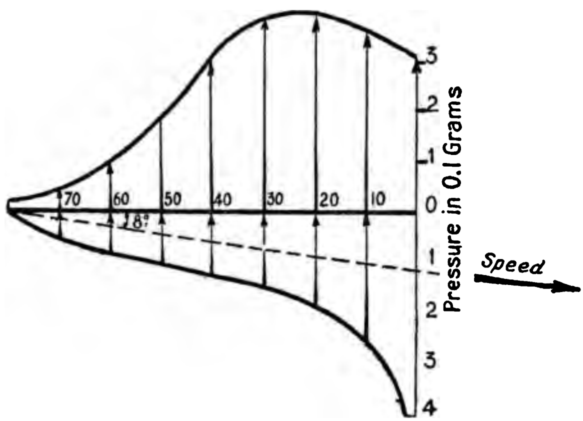

FIG. 4. Diagram of a Plane 80 Centimeters (32 Inches) in Depth. Angle of Attack, 8°. Speed, 10 Meters (33 Feet) per Second.

If the pressures are measured at different points on both faces, in the plane of symmetry, along the line of greatest inclination *AB* (Fig. 3), the following phenomena appear.

On the *lower face* the pressure is the greatest near the leading edge and gradually diminishes to zero near the trailing edge.

On the *upper face* the greatest suction is not at the leading edge, but some distance from it. This suction diminishes gradually to near the opposite edge and, if the plane is wide enough, counter-pressures may even appear.

If, on the perpendiculars to the plane, ordinates are drawn proportional to these pressures, a cer-

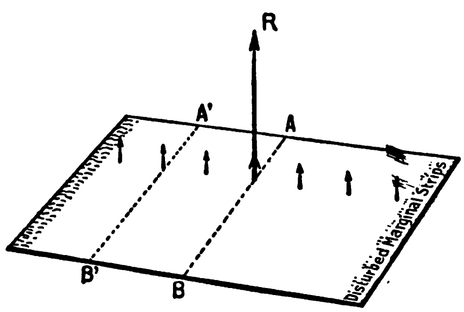

FIG. 5. Resultant of the Pressures R, and the Disturbed Marginal Strips

tain number of points are obtained enabling us to trace the two curves which give us the diagram of the plane under consideration (Fig. 4).

To the right and to the left of the middle line, on A' B' for example, the same figure is produced, identical, always excepting the lateral edges, which are a source of disturbance (Fig. 5).

The movement of the plane causes, at these points, disturbances, the effect of which makes

itself felt on the lateral strips, which are of practically constant width and independent of the dimensions of the plane. Whence it follows that,

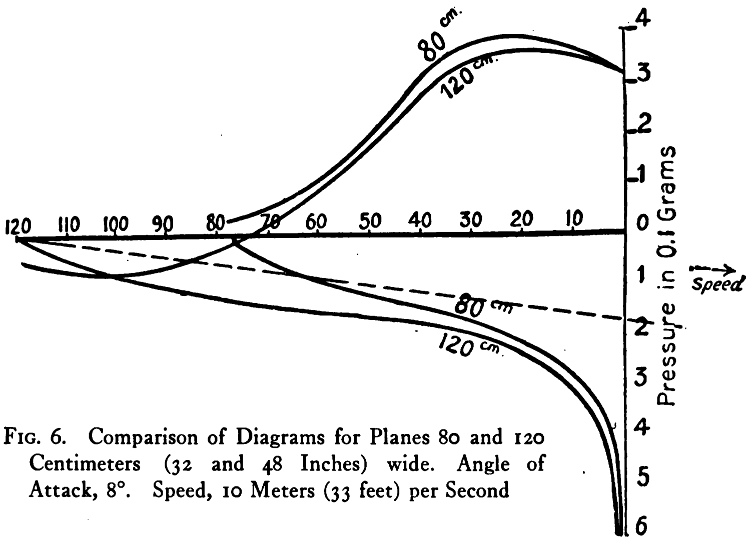

Fig. 6. Comparison of Diagrams for Planes 80 and 120 Centimeters (32 and 48 Inches) wide. Angle of Attack, 8°. Speed, 10 Meters (33 feet) per Second

for long enough spans, the influence of these strips is negligible and the pressure may be considered constant along a given horizontal line.

If the span is several meters, it is sufficiently accurate to consider the action of the air as proportional to the span. A plane with a span of 45 feet, accordingly, undergoes a stress three times as great as a plane of 15 feet.

To the contrary, an increase of depth is not

necessarily accompanied by a corresponding increase of lift. If, to a given plane, a strip is added parallel to the leading edge, this strip is subjected to very slight pressure on its lower surface. On the upper surface the zone of slight negative pressures (or suction) is extended, and even, for small incident angles (especially below 8°) counter-pressures appear, as may be seen on Figure 6 which combines the diagram of a plane 80 centimeters (32 inches) deep with that of a plane 120 centimeters (48 inches) deep, obtained by adding to the first a 40-centimeter (16 inches) strip parallel to the attacking edge.

It is evident, therefore, that a *plane* surface to be entirely "active," must not be much over 1 meter (or 3 feet) deep. It is also evident that the surface cannot be defined by the relation of the span to the depth. By doubling the dimensions of a plane the proportions are not changed but, by doing so, new phenomena are nevertheless introduced, which modify the whole distribution of the pressure. In fact, the air waves, produced by the motion of a surface, have their own period and their action varies greatly with the extent of the surface in contact with them.

Since all the forces acting upon a plane are always parallel, they may be resolved into a single

force of known direction, which is the resultant *R*. The position of this resultant is determined by the point where it passes through the plane. It is customary to call this point the "center of lift."

Angle of Attack. — Leaving the dimensions of the plane fixed for the present, let us vary the angle of attack. The distribution of the pressure changes completely. For each angle of attack there is a corresponding pressure diagram.

The resultant of these pressures varies in magnitude and in position. It may be said in a general way that it increases with the incidence and that its point of application, or center of lift, recedes, under the same conditions, from the front or leading edge.

At small angles it is situated nearly one quarter of the depth from the front edge and continues to move back till, at 90° of incidence, it is at the center of the plane.

Law of Squares. — On a given surface, in motion, whose angle of attack is constant, the pressures vary with the speed, but not in a simple ratio. For a speed, two, three, or four times as great, the pressures, positive and negative, at each point become four, nine, or sixteen times as great, which

is expressed by saying that the pressure at any point of a moving surface is proportional to the square of the speed, whatever the dimensions of the surface.

The resultant of all the pressures varies also as the square of the speed, but since the elementary forces which compose it all vary according to the same law, the point of application of the resultant, or center of lift, *does not change.*

In brief, the resultant depends:

1. On the span and depth. It is proportional to the first, but not to the second.
2. On the angle of incidence.
3. On the speed, which exerts an influence proportional to its square.

Curved Surfaces. — The air dynamics of plane surfaces have more than a theoretical value, because plane surfaces are used for rudders and elevators. Furthermore, the phenomena observed on plane surfaces also occur on curved surfaces.

1. The span and depth perform, as on a plane surface, separate rôles. (For curved surfaces the maximum depth depends, to a certain extent, upon the profile chosen. But, in a general way, experience has shown that no

advantage can be gained by making the wings over 6 or 7 feet wide.)

2. For a given angle of incidence, the pressures are constant along any line parallel to the leading edge.
3. The pressure is proportional to the square of the speed.

Aside from these points of similarity new phenomena also appear. For a given expenditure of force, curved surfaces lift a much heavier load. It is for this reason that they are used as supporting surfaces on airplanes.

Their superiority is due to two causes:

1. The pressure beneath the wing and especially the suction or negative pressure above the wing are considerably greater. The advantage is quite marked at small angles. Therefore for equal areas they can carry greater loads. This may be seen from Figure 7, which represents approximately the distribution of the pressure on a good wing, with an attacking angle of 6° and a speed of 10 meters (33 feet) per second.

2. The component pressures, being normal to the surface, are not parallel to each other.

The composition of all these pressures gives a resultant *R*, the inclination of which to the surface depends upon the angle of incidence and the profile chosen.

The wing is thick. It has, to speak accurately, no point of intersection with the line of the result-

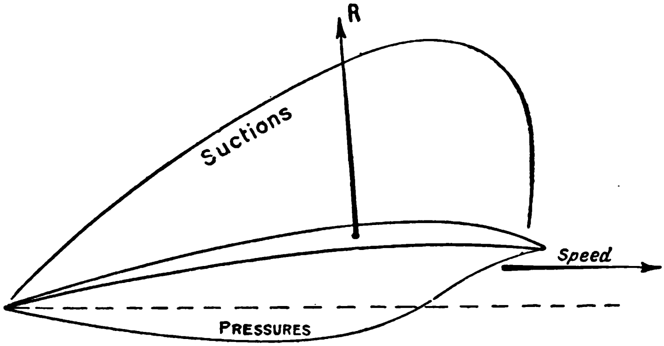

FIG. 7. Diagram of a Wing. Angle of attack, 6°. Speed, 10 Meters per Second. Scale: Pressure, 5 Millimeters per Millimeter of Water; Resultant, 5 Millimeters per Kilogram

ant. We may, then, consider it as the point of intersection of the resultant with the *mean* line of the wing (Fig. 7), or even with the imaginary plane *AB*, which serves to measure the angle of incidence (Fig. 10).

This resultant may be resolved into two forces, one of them perpendicular and the other parallel to the motion of the plane. We will call them

R_y and R_x. R_y is the *lift*, which is the useful component. R_x is the *drag*, the obstructing component.

We see on Figure 8 that $\frac{R_x}{R_y}$ has the same measure as the angle β, which the resultant makes with R_y, the perpendicular to the line of motion. The

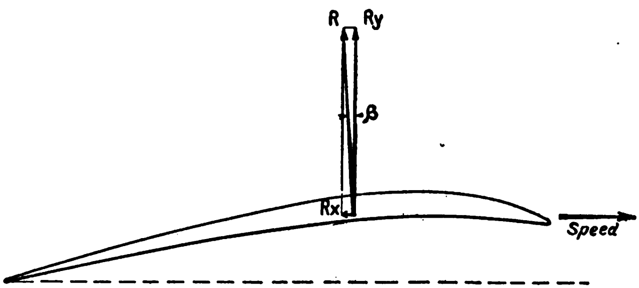

FIG. 8. The Resultant R is resolved into the Lift R_y and the Drag R_x

smaller this angle, the less the drag for a given lift. Thus, we can see that a wing profile is just as much better as the resultant R is (in flying at different angles of incidence) nearer to the perpendicular to the line of motion.

Angle of Attack of a Curved Surface. — When a plane surface moves through the air at an angle of 0°, it is subjected to no pressure. It was thought at first to define the angle of incidence

of a curved surface in the same manner. An angle of incidence of 0° would be the angle for which the lift of the surface would be zero. But the analogy is deceptive.

For a curved surface, the lift becomes zero at a negative angle of incidence of 4° to 6°, not, as in the case of a plane surface, because the pressure is zero, but because it creates two equal forces,

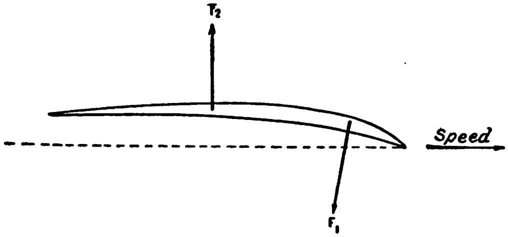

FIG. 9. Negative Angle of Attack for which the Lift is Zero

F_1 and F_2, with opposite signs (Fig. 9). Under these conditions the wing does not lift, but tends to rotate. Furthermore, it is difficult to measure this angle of attack.

The following method has therefore been generally adopted. Suppose the curved surface to be placed upon a plane surface AB and the angle of attack of this plane surface to be considered as that of the curved surface itself. It is then represented by the angle α, formed by the chord AB with the line of motion.

Optimum Angle. — Let us consider a curved surface, moving at a uniform velocity, whose angle of attack, at first zero, gradually increases. The

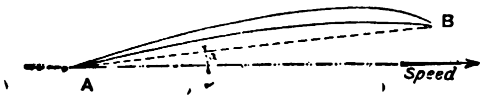

FIG. 10. Angle of Attack of a Curved Surface

resultant *R*, of the pressures, changes with the angle of incidence. Its point of application, its magnitude, and its direction vary. It increases

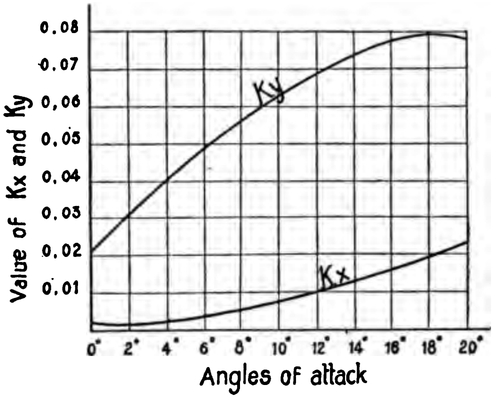

FIG. 11

in magnitude with the incidence, but, contrary to that which takes place in the case of a plane surface, it continues to move forward, at least till an incidence angle of about 20° is reached. At the

same time the surface rises in front and the direction of the resultant is thereby affected.

In order to study a curved surface we ordinarily have recourse to three graphics (Figs. 11 and 12), which represent respectively the value of R_x, R_y, and $\frac{R_x}{R_y}$, in terms of the angle of attack.

In practice R_x and R_y are reduced to their value per unit of surface. They are then designated by K_x and K_y.

We see, on Figure 11, that K_x increases much slower than K_y.

On Figure 12 we are able to follow the variation of the angle which the resultant makes with the perpendicular to the trajectory, since it is on this angle that the ratio of the drag to the lift $\frac{R_x}{R_y}$ depends, which is evidently equal to $\frac{K_x}{K_y}$.

As the angle of attack increases from 0°, experiments show that the resultant first approaches, in direction, the perpendicular to the trajectory, then inclines again to the rear. We see that the ratio $\frac{R_x}{R_y}$ grows less at first and passes a minimum M, which corresponds to the incident angle for

which the resultant makes the smallest angle with the perpendicular to the trajectory. This is the *optimum angle* for the given surface, usually included between 3° and 4° (Fig. 12).

The value of $\frac{R_x}{R_y}$ at this angle of incidence is, for good wings, about 0.06. In other words, at the optimum angle of attack, if the given surface exerts

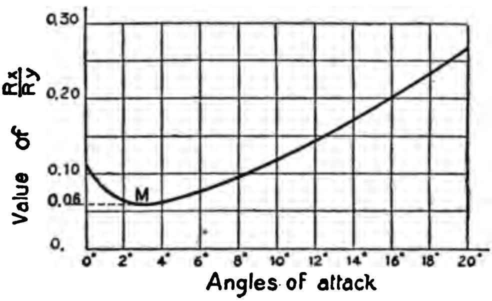

FIG. 12

a lift of 100 pounds perpendicular to its trajectory, it is necessary to apply to it a pull of 6 pounds.

In the case of a complete airplane the optimum angle of flight is a little larger, on account of the additional resistance coming from the passive parts of the machine, and which increases the drag. The pressure resultant, measured no longer on the wing alone, but on the whole airplane with increasing angles of incidence, gives for the values

of $\frac{R_x}{R_y}$ a curve similar to that of Figure 12, but the minimum value occurs at 5 or 6°. The aviator, to come under the most favorable conditions, must fly at this angle of incidence.

The *ratio of drag to lift for the optimum angle* has greatly diminished, owing to improvements being constantly made in wing profile, shape of body and landing gear, stream-lined profile of all projecting parts, struts, stays, wheel coverings, etc. The value of $\frac{R_x}{R_y}$, admitted three or four years ago to be in the vicinity of 14 per cent, on the best airplanes, has dropped, for certain machines, to 12 per cent. This coefficient is said to measure the *fineness* of the airplane.

Wing Construction. — After having shown what forces act upon the wings, it now remains to explain their construction.

1. The wings must have a surface area corresponding to the weight to be lifted. They may be small, if the airplane goes very fast, since we have seen that the pressure increases according to the square of the velocity, but in fact, an airplane, to be manageable and a good glider, must not be loaded more than

40 to ·45 kilograms per square meter (7 to 8 pounds per square foot).

2. They must be rigid, light, and firmly attached to the body.

From the above conditions has been derived the present style of construction.

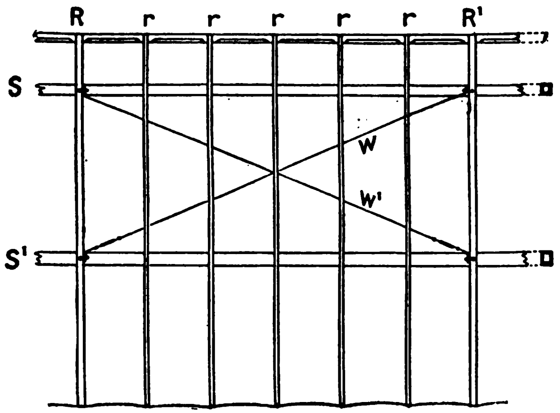

FIG. 13. Wing Section. *S*, *S'*, Spars. *R*, *R'*, Main Ribs. *W*, *W'*, Steel Wires

The wings are made of cloth stretched over rigid frames, each consisting of two strong spars, *S*, *S'* (sometimes three), connected by ribs which, at the same time, determine the profile of the wing. The rectangles formed by the spars and main ribs are braced by two steel wires *W*, *W'*, which hold them rigidly in place (Fig. 13).

Between the main ribs are interposed the ordinary ribs, *r*, similar but weaker, at intervals of about 30 centimeters, or one foot. They are all attached, in front, to a strip of wood which forms the leading edge; and, at the back, to a wire or strip of wood which supports the canvas covering.

This covering is fastened to the ribs by copper tacks. The wing, when finished, is covered with

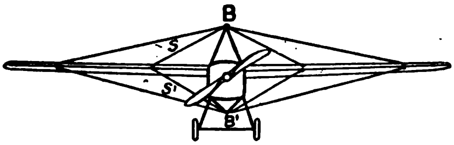

FIG. 14. Wing Stays of a Monoplane. *B*, *B'*, Braces. *s*, *s'*, Stays

a varnish, containing acetate of cellulose, which stretches it and, at the same time, renders it airtight and perfectly smooth.

The spars and struts are made of steel tubing, or of wood, partially hollowed out. The ribs are usually made of wood, but sometimes of steel, especially on controlling surfaces. The stays are of steel cable or piano wire.

Bracing the Wings. — In *monoplanes* the wing spars are fitted into the body and held by the stays, *s*, *s'*, attached to two braces, *B*, *B'* (generally called "cabane") above and below the cockpit (Fig. 14).

If the wings are lengthened, the length of the stays and consequently their obliqueness is increased, thus subjecting the wing spars to a compression which, should it become excessive, would render them liable to break.

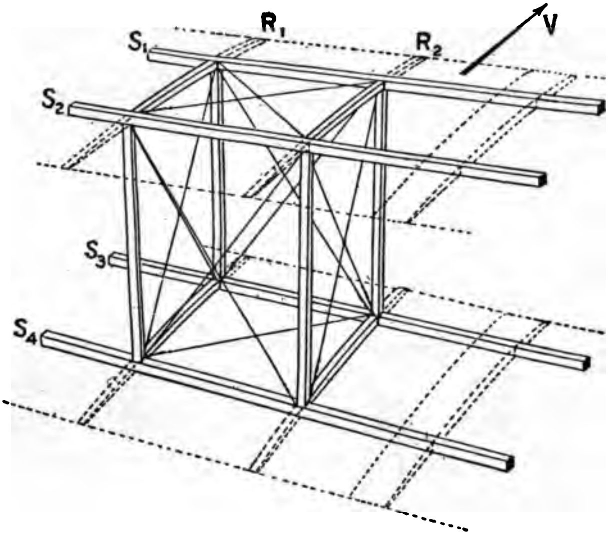

FIG. 15. Cell of Chanute. S, S_2, S_3, S_4, Wing Spars. R, R_2, Main Ribs

Fastening the wings of a *biplane* is quite a different matter, and this is one of the reasons of its superiority. The two wings, securely joined to each other, constitute a braced girder and mutually strengthen each other.

All the present biplanes are derived from the cell advocated in America by the Frenchman Chanute, of which the first application was made by the Wright brothers.

The cell of Chanute consists of four spars S_1, S_2, S_3, S_4, (Fig. 15) held in place by the struts and main ribs R_1, R_2. Each rectangle thus formed is crossed by a steel wire, as shown in the figure. The structure thus obtained is light and rigid, at least so long as no part is broken.

In contrast with the monoplane the cell is therefore rigid of itself and is simply attached to the body, upon which, however, it does not depend for its solidity.

In this cell the two horizontal faces are formed by the wings. If the distance between them is not less than their depth, they work almost as well as if they were separate. The effective span of the airplane is thus doubled.

Experiments have shown (as has already been stated) that the depth of the wing must not exceed a certain limit of about six feet. It is, therefore, the *span* that must be increased with the load to be raised.

In order not to reach too large dimensions, it was natural to attempt to increase the number of wings. Triplanes have been recently con-

structed. They consist of two superposed cells, having one face in common.

The multiplane, forming a rigid structure, is apparently the airplane of the future. But the mutual action of the wings upon each other is as yet too little understood for us now to determine the best mode of construction.

All the stresses of tension or compression, to which each part (wire, strut, spar) is subjected in normal rectilinear flight, are determined by graphical statics. Measurements made in full flight of the tensions of the various stays have confirmed the accuracy of the calculations for rectilinear flight. In turning, the tensions increase and experiments have enabled us to measure the increments. The design for an airplane can thus be made with the same precision as the design for a bridge or any other girdered structure. Knowing the strength of the materials and a certain coefficient of safety having been decided upon, the dimensions of each part can be mathematically determined.

Warping; Wing Flaps. — Foreseen by Penaud and Mouillard and applied by Ader in France (Chalons, 1897) and by Langley in America (on the Potomac) at about the same date, warping

was first practically utilized by the Wright brothers. It was this great innovation that made aviation possible.

Warping consists of a differential deformation of the wings which progressively increases the incidence of one of them, while it diminishes the incidence of the other. It is accomplished by making the rear wing spar oscillate about its middle in such a way as to raise one end while

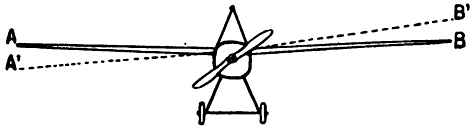

FIG. 16. Warping. *A′B′*, Projection of Rear Wing Spar

lowering the other. During this movement the front spar remains fixed.

By referring to Figure 16, which is a cross section of an airplane perpendicular to the body, we see in *AB* the projection of the stationary front spar and of the movable rear spar. Warping, without affecting the front spar, causes the rear spar to change from the normal position *AB* to the position *A′B′*. We see that the incidence of the wing *A* increases, while that of *B* diminishes, thus making the action of the two wings different. The wing *A* will then exert a greater lifting force

than the wing *B*. The pilot can thus modify his transverse equilibrium.

Instead of the method of warping which required a twisting and strain of the whole wing, we now prefer the action of two wing flaps ("ailerons") oscillating about the rear wing spar, which itself remains stationary. These flaps are paired in such a way that when one is raised the other is lowered. Their motion affects not only

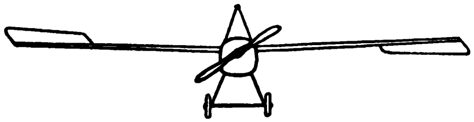

FIG. 17. Action of the Wing Flaps (Ailerons)

their own surface, but changes the distribution of pressure across the whole depth of the wing; the wing flaps, to be efficient, should extend at least half the length of the span. They are operated by means of steel cables or a rigid control.

Rudder and Elevator. — The *rudder* usually consists of one plane (sometimes more) oscillating about a vertical axis.

The *elevator* consists of a plane oscillating about a horizontal transverse axis.

(We will see further along the advantage of not using the elevator as a supporting surface.

It must therefore be parallel to the wind in normal flight.)

The rudder and elevator should be "compensated" as fully as possible. That is to say, the resultant of the thrusts must, at the ordinary angles, pass through the axis of rotation of the rudder or elevator, which is then in neutral equilibrium. This resultant is not fixed: the axis is

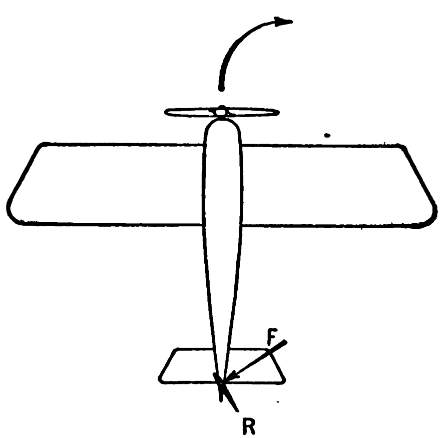

FIG. 18. Position of Rudder, *R*. Action of Air, *F*

therefore placed in the mean neutral position for small angles of incidence. When a machine is well constructed whatever positions are given by the pilot to the rudder or elevator should be readily maintained without special effort.

Action of Rudder and Elevator. — The *rudder* works in the same manner as that of a boat. If the pilot turns the rudder in the right direction, *R*, for instance, the air exerts upon it a force *F* which causes the airplane to turn in the same direction (to the right, in Fig. 18).

The *elevator* determines the angle of attack by causing the airplane to turn about the horizontal

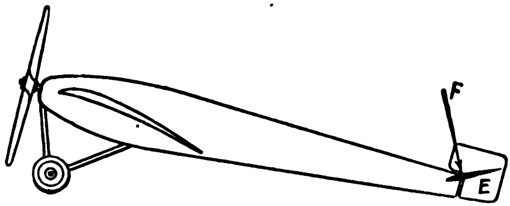

FIG. 19. Position of Elevator *E*, while Climbing

axis passing through its center of gravity. According to whether the air exerts upon the stabilizer a downward or upward push, the fuselage will point upward or downward and the incidence of the wings will be increased or diminished. We see on Figure 19 that, if the elevator *E* is raised, the air exerts upon it a force *F*, which depresses the rear of the airplane.

The same result may be obtained by leaving the fuselage parallel to the wind and causing the angle of attachment of the wings to vary during flight.

This method has been successfully employed under the term "variable incidence," but involves mechanical complications and an increase in weight. As a matter of fact the elevator is sufficient to change the angle of attack, which, with machines now in use, may vary from 0° to 16°.

Controls. — The rudder is controlled by the feet, by means of a rudder-bar or pedals.

The elevator and the wing flaps are controlled by hand. A lever attached to the floor of the cockpit enables the pilot to regulate the attacking angle of the elevator. Then he pushes the lever forward, the elevator is depressed, becomes a lifting surface, and raises the tail of the airplane, thereby causing it to dive head foremost. In order to climb, the lever must be pulled back.

The warping is accomplished by two different methods.

1. The lever in question is mounted with a universal joint and can oscillate from right to left. When inclined to the right, it lowers the left wing flap. The left wing becomes more supporting and rises, thereby causing the machine to dip to the right.
2. The lever remains in the plane of symmetry of the machine, but carries a control wheel

which, by means of a cogwheel and transmission cables, controls the movements of the wing flaps. (While turning the control wheel to the right, for instance, the airplane will dip to the same side.)

Passive Elements. — We recall that these are the body or fuselage and landing gear.

Airplane *bodies* differ according to the number and position of the engines. In general the form to give the body is that which will least impede its motion through the air. Such is a fish-shaped body, largest at about one quarter from the front and tapered toward the rear.

If the engine is placed in the front part of the body, the latter may be prolonged toward the rear in order to support the rudders. Thus we have a continuous solid, which affords excellent penetration, but the engine interferes to a certain extent with the view of the pilot, while the propeller is an obstacle to firing directly in front.

In the case of a pusher, the engine is in the back part of the body, which is therefore interrupted by the propeller. We must then have recourse to two lateral girders to support the rudders. This arrangement gives a broad field of vision, but introduces passive resistances which reduce

the speed of the airplane. The engine behind the pilot is also a source of danger in case of a bad landing, and the propeller interferes with shooting toward the rear.

These obstacles have been partially overcome by devices which are not without their faults, so that the resulting gain is quite small. Airplanes with several engines require several bodies, thereby increasing the air resistance.

The *landing gear* performs a double function. It enables the airplane to roll on the ground in starting to fly and it softens the shock of landing.

It is the landing which develops in an airplane the greatest stresses. The alighting airplane still has considerable velocity which is naturally in a downward direction. The landing gear resolves this velocity into two others: one horizontal, causing the airplane to roll along the ground; the other vertical, softened by flexible connections, rubber strips, or spiral springs.

The two most common types of landing gears are:

1. Two or four wheels placed abreast under the front end of the airplane, which, on stopping, rests also upon the skid *S*. It is then in a climbing position (Fig. 20).

On starting, as soon as the machine begins to roll, the skid leaves the ground and the pilot maintains the longitudinal equilibrium by means of the elevator. In landing, the machine is braked by the skid and by increasing the incidence of the wings.

2. When the engine is in the back part of the body, the flattened position at the moment of

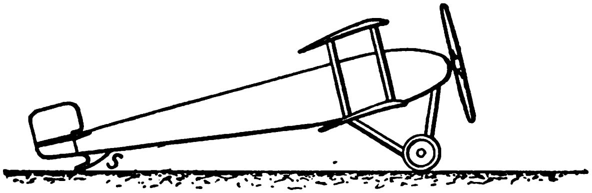

Fig. 20. Landing Gear, with Skid *S*

landing brings the propeller near the ground. If it is still rotating, the least obstacle may damage it. Accordingly airplanes of this type often have a different kind of landing gear. Four wheels are attached to the bottom of a rectangular frame upon which the airplane rests, as upon a carriage (Fig. 21). Gabriel Voisin invented this type of landing gear.

While rolling on the ground, the angle of incidence is determined. The machine leaves the ground as soon as it has acquired sufficient speed.

After landing, the pilot applies the brakes to the wheels to stop the machine.

In the case of hydro-airplanes or seaplanes we find the same problem of alighting, but complicated by the fact that the machine, if forced to

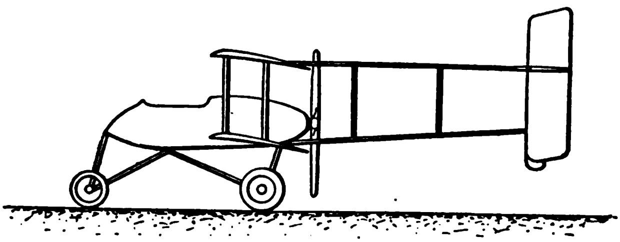

FIG. 21. Voisin Landing Gear

alight on the high seas, must be able to float in rough weather.

The first seaplanes were simply land machines, on which the wheels and tail skid were replaced by three floats. The Caudron brothers even constructed a combination machine with landing wheels attached to the floats. The machine could then alight equally well on land or water.

These expedients are unsatisfactory, where a hydro-airplane is expected to withstand rough seas. In such a case the balancing of the machine upon two floats is precarious, and becomes perilous if it is stranded. The waves would then cause

the machine to oscillate, with the danger of puncturing one of the floats.

The use of the flying boat would appear preferable. Such seaplanes are capable of keeping the water in severe weather.

Coefficient of Safety. — In any work of construction the stresses to be undergone must be provided for by the designer. In calculating all its elements these stresses are supposed to be multiplied by a certain number called the "coefficient of safety." The coefficient of safety of a bridge, for example, is ten, if it is capable of supporting, before breaking, a load ten times as large as it is liable to be subjected to in ordinary use.

This definition of coefficient of safety is not entirely applicable to airplanes, for, although the loads to be supported by the wings in normal flight are known, we can hardly estimate the additional stresses produced by the gusts of wind, and still less those caused by the acrobatic stunts of the pilots and their faulty maneuvers (bad landings, for example).

In fact, it is admitted that the wings must, before breaking, be able to resist a stress at least six times as great as that required to support the weight of the airplane under normal conditions.

They are tested as follows. The cell is inverted and a layer of sand is spread in the hollow of the wings. The machine should be so placed that the weight of the sand will act in the same way as the air acts during flight, in causing pressure and suction. This means that the action of the force

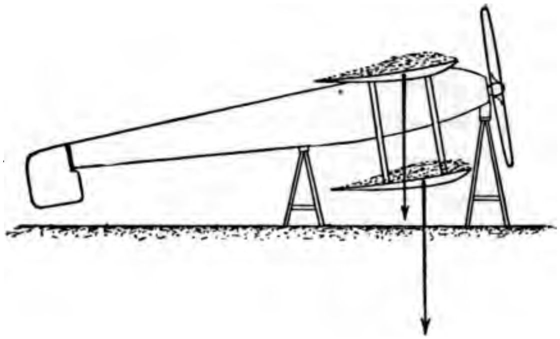

FIG. 22. Resistance Test

of gravity will be in the same direction during the test as that of the resultant action of the air on the wings during flight, as seen on Figure 22. The body of the airplane must, therefore, be inclined. In practice the tests are now made with the wing cord at an inclination of 25 per cent to the horizontal.

This test is completed by spreading a certain load of sand on the upper side of the wing, with the machine in its normal position. It may hap-

pen, in fact, that the angle of incidence will become negative, and the wing, receiving the force of the air on its upper surface, must be able to withstand the resulting pressure.

These static tests are of the greatest importance. They expose the weak points of an airplane and must be tried with a model of every new series.

It was customary to require of airplanes a safety coefficient of four for permanent deformation, which corresponds to six or seven for breaking. At the present time, with the increasing speeds, the breaking coefficient should be at least six, and in some cases nearer ten.

A cell that has undergone static tests cannot be further used in flight, even if no permanent deformations have been produced.

CHAPTER II

THE PROPELLER

THE first thought that comes to the mind is to compare an aërial propeller to that of a boat. But the two cases are not identical. Air is highly compressible, while water is practically incompressible. Experiment and theory have gradually modified the shape of the blades. Originally consisting of a simple blade of twisted metal, they have become thick, with the cross section of the blade similar to that of an airplane wing.

Without taking up the complete theory of propulsion, which is beyond the limits of this work, we will show that the shape of the propeller depends upon the conditions under which it is to be used. To a given airplane, equipped with a given engine, a certain style of propeller is adapted. Hence the impossibility of getting along with only one type of propeller.

Thus a propeller cannot be removed from a given type of airplane and used on an airplane of

a different type. This organ is so sensitive that even for the same airplane one propeller must be chosen for a low altitude and a different one for

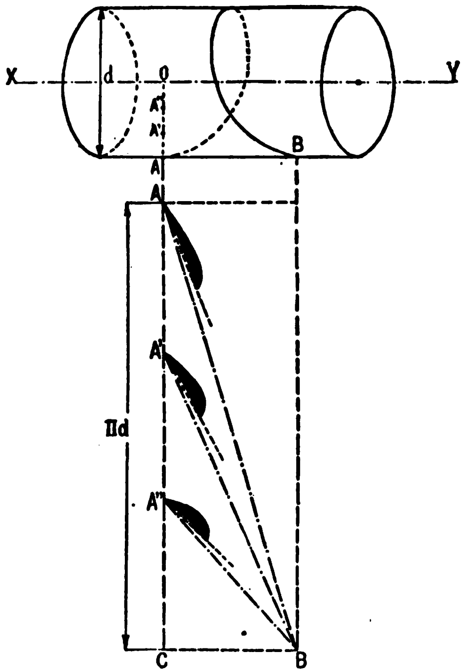

FIG. 23. Development (unrolling) of the Helix. *AC*, Development of a Straight Section of a Cylinder. *A*, *A'*, *A''*, Different Cross Sections of the Blade

swift climbing or flying at a high altitude. Recently experiments have been made with propellers so constructed that their deformation during flight

will automatically adapt them, to a certain extent, to these varying conditions.

A propeller is a warped or twisted wing. The double principle already explained of the attacking angle and the optimum angle will enable us to understand its working.

Geometrical Helix. — The geometrical helix may be obtained by winding a straight line about a cylinder, which may be expressed by saying that a point describes a helix when it revolves about an axis, while remaining at a constant distance from this axis and moving parallel to it a distance proportional to the angle it has turned.

This point, while describing a complete circumference about its axis, advances a certain distance, which is called the "pitch" of the helix (Fig. 23). The point moving from A to B describes a spiral about the axis XY, and the distance AB measures the pitch. Projected on a plane perpendicular to the horizontal axis, the point has traversed a circumference of diameter d, or a distance equal to πd. The helix developed upon a plane becomes the straight line AB, of which the projection AC is equal to πd, as already stated.

An example of helical motion is given by a screw entering a nut. The screw is threaded, that is,

provided with a certain number of spirals, all having the same form and pitch.

Airplane Propeller. — What do we find of all this in the airplane propeller? Let us suppose that OA represents the blade of a propeller, the axis of which is XY. If in one second the airplane advances V meters while the engine makes n revolutions, $\frac{V}{n}$ would be the pitch of any point of the propeller. The end of the blade moves from A to B. AB is the path or trajectory of the end of the blade and BC represents the pitch. For each section of the blade there will be a special trajectory $A'B$, $A''B$. The pitch BC remains the same, although the distance d of the cross section from the axis diminishes. In order for the propeller to work under the best conditions, the sections of the blade A, A', A'' must, in their respective trajectories, attack the air at the optimum angle of incidence. A propeller, therefore, consists theoretically of a series of wing sections, to which is given in the first place an inclination imposed by the pitch and which grows less as the distance from the hub increases. This angle is further modified in order to give to each section of the blade the most favorable angle of attack

for its particular trajectory. Problems of construction cause variable profiles throughout the length of the blade, so that the optimum angles for various sections vary slightly, especially near the hub.

Constructors make a practice of marking the pitch upon each propeller, after the diameter. This practice has no value, excepting for a given firm to classify its own propellers. This pitch is measured as follows: the propeller is placed upon a steel plate and the inclination of the blade is measured by means of a protractor at a fixed distance from the hub of usually 1 meter (3.3 feet). Multiplying the angle thus obtained by the circumference described, gives a length which, *for convenience*, is called the *pitch*. If, moreover, this operation is repeated at several points, different values are obtained. Such a propeller, with a diameter of 2.9 meters, has a pitch varying from 1.8 to 2.5 meters.

The optimum angle is known to vary according to the cross section chosen, and experiments have shown that just as good propellers can be made with different profiles, as well as diameters. So that propellers equally well adapted to a given airplane may have different pitches, according to whether they are made by this or that constructor.

To summarize, in order that a propeller may be used under good conditions, it is necessary for each part of the blade to attack the air at a certain angle. If the propeller is well made, this condition being obtained for one of the points of the blade, the end, for example, it will be obtained for each of the sections. We have seen that the angle of attack for the end of the blade depends upon $\frac{V}{nd}$. This ratio must, therefore, remain constant for a given propeller. Since the diameter, d, of a propeller does not vary, $\frac{V}{n}$, the ratio of the speed of the airplane to the number of revolutions per minute, must be invariable.

If we now consider *similar propellers* with different diameters, $d_1, d_2 \ldots$ the angles of attack of the corresponding sections will be the same, especially that of the end of the propeller, which depends upon $\frac{V}{nd}$.

We will then have:

$$\frac{V_1}{n_1 d_1} = \frac{V_2}{n_2 d_2} = \ldots = \frac{V}{nd}$$

Since the diameter of the propeller is given, the forward speed (V) or the number of revolutions

per minute (n) must be varied in order to give the ratio its proper value. The two variables are determined by testing the propellers on a car drawn along a track.

Work. — Work is done upon a body when that body is moved against some resisting *force*. The *work* thus *done* is measured by the product of the *force* and the *distance* the body is moved. The practical unit of work is the foot-pound, which is the work done in moving a body one foot against a resistance of one pound. An engine is designated by its power, that is, by the number of foot-pounds of work it can do in one second.

The commercial unit of power is the horse power (HP), which is 550 foot-pounds per second. An engine of 1 HP can lift, in one second, 550 pounds to a height of 1 foot, or one pound 550 feet. In general, either one of these factors may be fixed. The other will be such that the product of the two remains constant.

Thus, a propeller which exerts a pull of 550 pounds upon an airplane moving 100 feet per second absorbs a power of $550 \times 100 = 55{,}000$ foot-pounds, or 100 HP. It would absorb the same power in imparting a speed of 125 feet per second to an airplane offering a resistance of 440 pounds.

Efficiency of the Propeller. — The power is furnished by the engine and is transmitted by the propeller, which, like all machines, dissipates a certain portion of it. The efficiency of the propeller is the ratio of the power transmitted to the power received. If, for example, a propeller is mounted on a 100-HP engine and only transmits 80 HP to the airplane, its efficiency is 80 per cent.

The total efficiency of the propeller results from the combined efficiency of all the sections of the blade, which depend, themselves, upon two factors. In proportion to the distance from the hub the warp of the blade causes the resultant of the air pressures on each successive section of the blade to become more and more nearly parallel to the axis of the propeller. But, on the other hand, the leverage increases and the effort to overcome the drag of the blade is greater. Under the influence of these two causes the efficiency varies throughout the length of the blade. It increases at first and then diminishes, the extreme values being included between 70 per cent and 88 per cent.

A well-designed propeller can give a high efficiency, even surpassing 80 per cent in some cases. But an airplane must fly under greatly varying conditions, both of ascending flight and horizontal flight at different altitudes.

In practice, the propeller is selected for horizontal flight at the average altitude at which it is expected to fly. Even under these conditions, the best shape to give the propeller has not been definitely determined. An airplane, in fact, expends fuel and constantly diminishes in weight. If the pilot utilizes the whole power of the engine, he will be compelled to fly, in order to remain at the same altitude, under constantly decreasing angles of incidence, and the speed of the airplane will increase; but there is only one speed at which the efficiency of the propeller is at its maximum. An airplane should therefore, theoretically, have a *set* of propellers, or a flexible propeller which would continually adapt itself to the conditions of flight.

Propellers have been used, notably on dirigibles, with variable pitches, that is to say, with blades that can be placed at different angles of incidence on the hub. The problem is not solved by this device, for the angles of attack of all the segments are thus increased in the same degree, although they should be increased by a quantity proportional to their distance from the hub. In practice we are contented with an average solution, and on the whole satisfactory, since the output of the propeller reaches 78 to 80 per cent, which gives

the present airplane superiority over any system with flapping wings, so often proposed.

Measurement of Efficiency. — The efficiency can be measured on a car which the propeller, run by an electric motor, pulls on rails. The angular velocity and pull of the propeller and the speed imparted to the car are measured, and a watt-meter shows the electrical energy furnished to the motor. Thus we have all the required conditions for solving the problem. The electric motor car was first used by Colonel Dorand in the "Laboratoire d'Aéronautique Militaire" at Chalais-Meudon, then at the "Institut Aérotechnique" of Saint Cyr for thorough investigations of the best forms to give to propeller blades.

Propeller Construction. — Propellers are generally of walnut, a sufficiently elastic and non-warping wood. They are not made from a single timber (which would cause the grain of the wood to be cut, especially near the hub), but from a series of strips not over an inch thick, arranged like steps (Figs. 24.) Moreover, it is less difficult to find sound strips when they are thin.

The strips are joined by strong hot glue which is free from acids, or better still by casein glue. The propeller thus made offers great resistance

to bending and is very slightly deformed by atmospheric conditions.

After having been brought to the desired form by the use of the gouge and plane, the propeller is balanced in all its positions and lastly given a coat of "filler."

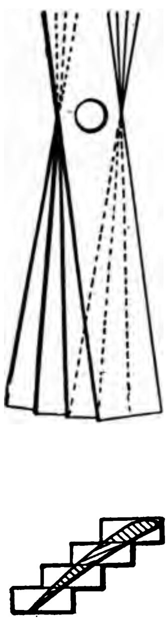

FIG. 24. Propeller Construction

A new method has been employed which seems to have given excellent results and which could doubtless be extended to other objects besides propellers. Strips of wood hardly more than a quarter of an inch thick are fastened to a solid die having the form of the attacking face. These wood strips, with strips of linen between them, are glued together with casein glue. After being under pressure for three or four days, the propeller is practically indeformable. There is nothing more to do, excepting to dry out the water from the glue and to shape the back of the blade, which is already very nearly of the required shape.

A propeller thus constructed is very strong and solid. A bullet or piece of shell can make a hole in it without splitting it.

The propeller is secured to the engine shaft by a metal hub or "boss," with cone and key (Fig. 25). It is securely held by the hub, by means of bolts (usually eight in number) which pass through the wood and secure it to the hub flanges.

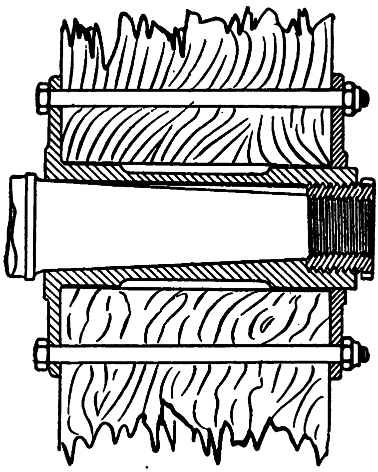

FIG. 25. Propeller Hub or Boss

This form of mounting, derived from that of the removable wheels of motor cars, has the fault of being a little heavy. We seem to be on the road to make a lighter device. The engine shaft is prolonged by a cylindrical sleeve with a flange. The propeller has on the front side a circular plate corresponding to this flange. The propeller is

firmly held between these two by a certain number of bolts.

A chipped propeller can be repaired. The break is first smoothed out; then a new piece is fitted (by rubbing chalk on the piece to be fitted) and afterwards glued and pegged with bamboo.

Vibrations. — An airplane in flight is often the seat of vibrations which disturb the pilot and strain the machine. They are always due to the power plant, that is, to the engine or to the propeller. In the latter case there may be three causes:

1. Poor balancing.
2. The two blades may differ in shape, although balanced in weight, so that the action of the air is not the same on both blades and the center of pull is not at the center of the propeller. In both cases, these faults of construction must be corrected.
3. The two blades of a perfect propeller may be subjected to different stresses, if their forward speeds are not the same, due to either a horizontal or vertical change of direction (turning or looping), or to the effect of a lateral gust of wind striking one blade before the other. This last effect is only momentary,

but we must remember that every acrobatic performance increases the vibrations and fatigue of the machine.

The Propeller Couple. — The engine, in impressing its motion upon the propeller, undergoes, according to a well-known principle of mechanics, an equal reaction which tends to rotate the cell, of which it is a part, in the opposite direction. This reaction is easily counteracted by a slight displacement of the wing flaps. For an engine of 100 HP the couple has a value of about 100 kilogram meters. This is only an average value, as the couple (or "torque") varies with the number of revolutions per minute. The effort required by the wing flaps to maintain equilibrium is inversely proportional to the distance from the longitudinal axis of the airplane. If the span should have a length of ten meters, the required force would then be one tenth of what it would be for a span of one meter, that is to say, only a few kilograms.

Airplane with Two Propellers. — On twin-engine airplanes now in use, two identical engines are placed on either side of the body. The propellers rotate in the same direction and their couples are added (Fig. 26).

The stopping of one or the other engine produces different results. If the left propeller P_1 stops, the airplane starts to turn to the left, which to a certain extent counteracts the diminution of the reaction R and contributes to the maintenance of the transverse equilibrium, until the pilot gives the wing flaps a position corresponding to the new conditions.

If the propeller P_2 stops, the tendency of the airplane to rotate and the position of the wing flaps combine to incline the airplane to the right.

From the above facts we can see the advantage of having the engines turn in opposite directions and be "*supra-convergent*" (Fig. 27), just the reverse of the arrangement on a steamboat, where, for other reasons, they are "*supra-divergent.*" This condition is easily obtained if the propellers are controlled by gearing, from a central engine.

If the airplane has sufficient reserve power, it can fly with either one of its two engines alone, but its height limit will naturally be lower. Calculation shows that this would be lowered about 3700 meters, other conditions remaining the same. This difference is, of course, diminished, if the airplane is relieved of a part of its load.

In case one of the propellers is stopped, in order to keep the airplane from turning, the pilot will

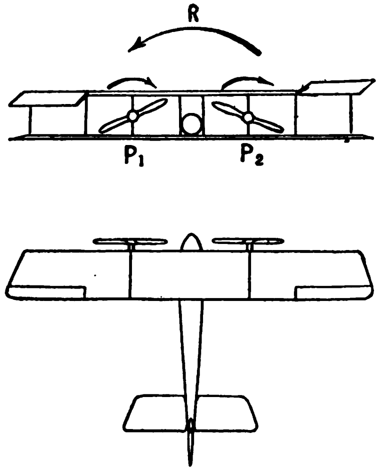

FIG. 26. Airplane with Two Propellers rotating in the Same Direction

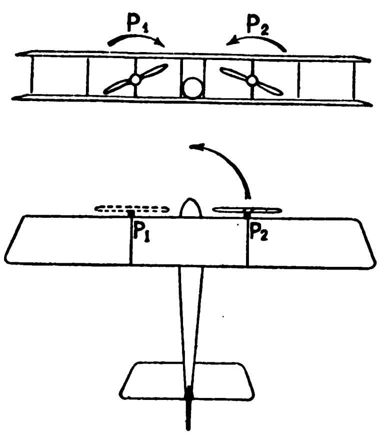

FIG. 27. Airplane with Two Propellers rotating in Opposite Directions

be obliged to constantly incline the rudder. If the left propeller, for instance, is still running, he must advance his left foot until the resultant of the forces coming from the pull of the propeller and the resistance of the rudder passes through the center of gravity *G* of the machine. This requires for the rudder a sufficient area of surface and

FIG. 28. Flying sidewise with a Single Propeller

a sufficient distance from the center of gravity of the airplane, which distance depends upon the length of the body. The body of a twin-engine machine must therefore be made longer. The airplane will then fly sidewise in the direction *GV* (Fig. 28).

The pilot can, moreover, by means of wing flaps, maintain a rectilinear course, parallel to the axis of the machine. By inclining the cell to the left,

in the present case, a force *F* is developed, which changes the direction of the airplane (Fig. 29). This

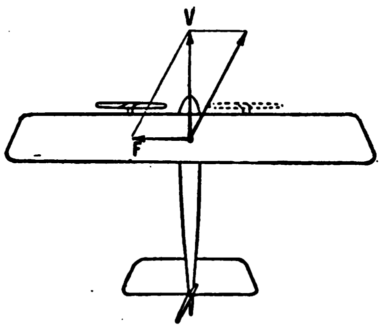

FIG. 29. Rectilinear Course with a Single Propeller

expedient has the disadvantage of diminishing the supporting power of the wings and consequently still further lowering the height limit of the airplane.

CHAPTER III

THE ENGINE

THE force required to drive the propeller is generated on the airplane by an internal combustion engine, similar to those on motor cars, but lighter. A mixture of gasoline and air, in certain definite proportions, is introduced into a cylinder, where it is compressed by an advancing piston and then exploded by an electric spark, which sends the piston violently down, and through the connecting rod imparts a rotary motion to the crank shaft. This crank shaft, held by thrust gearings, carries the propeller, which on airplane engines takes the place of a flywheel.

Let us first consider a *one-cylinder* engine and recall the phenomena accompanying the explosion of a gaseous mixture, the source of the energy we wish to utilize.

When we understand the working of the one-cylinder engine, we will be in position to examine the various engines in use, which differ only in the number and arrangement of the cylinders and in their method of cooling.

Four-stroke Cycle. — A cylinder consists essentially of a tube closed at one end by a cylinder head with two valves: the "intake valve," which admits the carbureted air; the "exhaust valve," which permits the exploded gas to be driven out through the exhaust pipe.

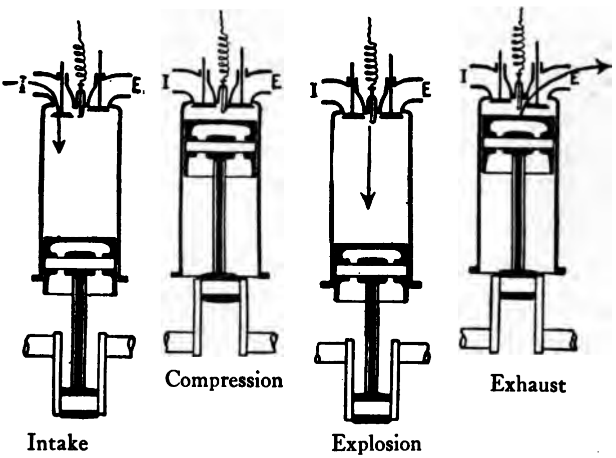

FIG. 30. Four-stroke Cycle. *I*, Intake Valve. *E*, Exhaust Valve

Let us suppose the engine to be running, with the piston at the top of its stroke, near the upper "dead center," that is, at the point where, having ceased to ascend, it is about to descend. There is in the cylinder only a little burned gas, left from the preceding explosion (Fig. 30).

1. *Intake stroke.* The piston descends, diminishing the tension of the gas behind it. The intake valve *I* opens, admitting the gas from the carbureter, until the piston reaches the lower "dead center."
2. *Compression stroke.* The upward stroke of the piston compresses the gas to about one fifth of its original volume.[1]
3. *Power stroke.* At this point the electric spark, generated by the magneto, explodes the mixture of gases and the piston is driven violently downward, thus producing the power that drives the crank shaft.
4. *Exhaust stroke.* Just before the piston reaches the end of its stroke, the exhaust valve opens and the gases are driven out, at first spontaneously from their excessive tension and then by the upward stroke of the piston.[2]

[1] The thermodynamic efficiency is just as much greater as the compression is more energetic. This is limited to four or five atmospheres in order to avoid premature explosion. The gas is heated by the compression and may ignite spontaneously before the piston reaches the end of its stroke.

[2] It must be noted that the opening and closing of the valves, as also the spark ignition, do not take place exactly at the dead centers of the piston. Theory and experiment have shown that there must be a slightly delayed closing of the intake valve, advancing of the exhaust and advancing of the spark. Each engine requires a very exact adjustment of all these points.

Of the four strokes enumerated, only one, the third, furnishes energy. The three others absorb it. In other words, of two revolutions of the shaft, only a half-turn furnishes energy. Hence the necessity of a regulating flywheel, or its equivalent, the importance of which diminishes as the number of cylinders is increased.

Engine Parts. — The principal parts of the engine are: the cylinder with its valves, the piston and piston rod, the crank shaft and crank case, the carbureter, and the ignition, lubricating, and cooling systems.

Cylinders. The airplane engine must be powerful and light. An engine gives power in proportion to the frequency and strength of the explosions. The power of the explosion depends upon the dimensions of the cylinder, but, other things being equal, if we wish to obtain a relatively high efficiency, that is, many horsepower for a given weight, it is necessary to have the engine rotate at a high speed of 1500 to 2000 revolutions per minute.

This condition, as we shall see, limits the dimensions of the cylinder. While some gas engines have cylinders 1 meter in diameter and make 100 revolutions per minute, airplane engines, like those of motor cars, have much smaller cylinders.

The capacity of a cylinder depends on two factors:

The *stroke* which is limited by the speed of the piston (above 10 meters [33 feet] of average speed, the stresses undergone by the parts with an alternating movement become considerable).

The *bore*, or diameter of the cylinder, which cannot exceed a certain value. The gases, at the moment of explosion, reach a temperature of 2000° C., so that the middle of the piston, if too far from the cool walls, would become overheated and determine pre-ignition. Up to the present time the cylinder-bore of airplane engines has not often exceeded five inches.

In practice, the stroke varies from 1.2 to 1.6 times the bore, or inside diameter of the cylinder.

For these various reasons the power developed by a single cylinder is limited. It has not yet exceeded 50 HP. We must, accordingly, if we wish to produce high powers, assemble a certain number of cylinders. But in this respect we are again limited by the necessities of construction. Up to the present time not more than 16 cylinders have been successfully assembled.

The cylinders are of cast iron or steel. Cast iron is easier to manufacture and softer for the piston. Steel, being stronger, makes lighter con-

struction possible; its use becomes necessary for rotary engines, on account of the great tension to which the cylinders are subjected by the centrifugal motion.

Valves. — The valves connect the inside of the cylinders with the intake pipe on the one hand and the exhaust pipe on the other. They must be strong, rigid, and firmly held in their seats by springs. Their motion must be rectilinear. For this purpose their stems move in sleeves, which guide them.

They are subjected to very rapid motions (sometimes as many as 15 or more lifts per second) and must be made of special steel, in order to be both light and strong and to stand the heat, especially the exhaust valve.

The valves are opened by cams operated by the engine. The intake valve could be automatic and simply respond to the suction of the downward stroke of the piston, at the end of which it would be brought back to its seating by a light spring. It is, however, mechanically operated in most engines so that it may be opened more rapidly and at exactly the right instant.

Piston. The piston moves inside the cylinder, carrying with it the connecting rod, by its small

end or "foot" *F* (Fig. 31). The piston has usually been made of cast iron, which gives a good gliding surface — sometimes of steel or aluminum,

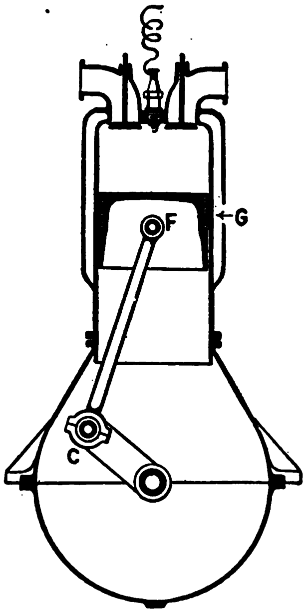

FIG. 31. Cross Section of a One-cylinder Engine. *F*, foot of Connecting Rod. *C*, Crank Pin

the use of the latter rapidly taking the place of both iron and steel.

The piston must be tight in order to prevent all leakage of gas at the moment of explosion. To accomplish this a certain number of grooves *G*

are cut round the outside of the piston, into which "piston spring-rings," of square cross section are fitted. These are made of slightly larger diameter than the bore of the cylinder and are cut through, sometimes diagonally and sometimes in the form of a step. Thus, when the piston is in the cylinder the rings are compressed. At the same time they are constantly trying to expand to their normal diameter, thus pressing tightly against the walls of the cylinder. The gas can then escape only through the cut in the ring, which opening is very small. With four or five rings, the gas-tightness is practically perfect.

When two or more rings are employed the slits in the rings must not be vertically over each other. They must set in different positions around the piston, so as to avoid as far as possible the escape of any gases past the slits as would occur were they in line. The ends of these rings must be some distance apart when cold ($\frac{1}{32}$ of an inch for a 4-inch piston), so as to allow for expansion when the rings became hot.

Inside the piston is set a steel "wrist pin," which is adjusted in the connecting rod's small end, the latter being lined with bronze or tempered steel to make it work smoothly on the wrist pin. The connecting-rod head carries the crank pin *C*. It is

lined with a fusible alloy of called white metal, or Babbitt metal, which melts in case of poor oiling, leaving sufficient play to prevent binding.

The *crank shaft* is a piece of wrought steel which rotates on stationary bearings and carries a crank pin between each pair of cranks. It transforms the thrust of the connecting rod into rotary motion. With each explosion it receives a violent impulse. It must be strong and rigid.

On engines with several parallel cylinders there are just as many crank pins as there are cylinders. Since the crank shaft transmits the energy of all the connecting rods, we can see that it is just as much more difficult of execution as the number of cylinders is larger.

It is inclosed in the crank case, which forms in a general way the housing for all the parts of the engine. Except in rotary engines the crank case is made of cast aluminum.

The *carbureter* is the gasometer of the gasoline engine. It is there that the carbureted air is produced which is exploded in the cylinder. This gas must have a definite composition, that is, a definite ratio between the weight of the air and gasoline, as explained further along.

The gasoline is sprayed into the intake tube

from the nozzle *N* (Fig. 32), as a result of the partial vacuum formed by the rushing of the air past it, through the narrow part of the tube, during the first downward stroke of the piston which draws the mixture of gasoline and air into the

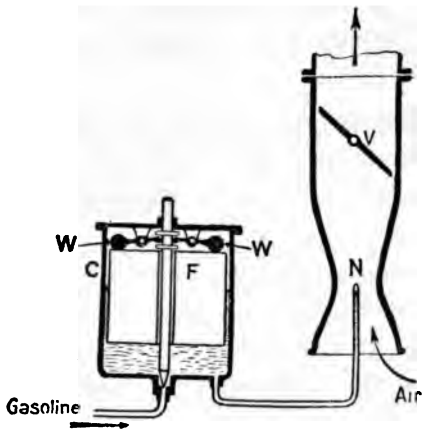

FIG. 32. Carbureter. *C*, Chamber which receives the gasoline. *F*, Float. *N*, Nozzle. *V*, Butterfly Valve

cylinder. The action is similar to that of a perfume atomizer.

The nozzle *N* is connected to a gasoline chamber of constant level *C*, in which there is a movable float *F*. Through the center of this float passes a needle, to which are attached two balance weights just above the top of the float. These weights are pivoted and rest on the top of the float. As

the gasoline rises in the chamber, the weights are pushed up and eventually allow the needle valve to drop back on its seating and thus stop the flow of the gasoline. The apparatus is adjusted so that, when not in use, the gasoline flows to within a few millimeters below the nozzle opening, ready to spray at the least suction of the engine.

The carbureter has a butterfly valve *V*, worked by the throttle, to vary the size of the gas passage, thus regulating the feed of the engine and accordingly its power.

The carbureter should produce a mixture of constant composition. This is a difficult problem, particularly in airplane engines. Several causes, in fact, may disturb the ratio of gasoline and air.

1. *Influence of variation of engine speed.* It is because the air is sucked in by the motion of the pistons that the variations of engine speed influence the carbureter. The pressure in the carbureter is thus diminished approximately as the "law of the squares," a common principle in all air dynamics. If it is not remedied by certain devices, the quantity of inhaled gasoline will vary accordingly. For example, if the engine triples its speed, the

pressure in the carbureter is diminished nine times and the evaporation of the gasoline is increased nine times, although it should be only tripled. Various means have been tried for automatically keeping the mixture constant for any speed of its engine. The problem has, however, never been completely solved.

2. *Influence of altitude.* On an airplane another complication arises. Even at the normal speed of the engine the carburetion may be disturbed. We know that the ratio of the weight of air to the weight of gasoline in the cylinder should remain constant. The weight of air evidently depends upon its density, which depends upon its *temperature* and *pressure.*

The influence of temperature alone, between 0° and 30° C. (32° and 86° F.) may vary the density of the air 10 per cent, but, on an airplane, the cooling of the air, which increases the density, takes place in ascending. This does not, however, entirely counteract the diminishing pressure, which at 2500 meters is not over three fourths of what it is on the ground. The carbureter then furnishes a mixture too rich in gasoline. This problem has also presented itself for motor cars on mountain trips.

Admission of air, automatic or not, diminishing the suction in the carbureter and consequently the amount of gasoline vaporized, is therefore necessary on an airplane for flying at high altitudes. Lacking which, the excess of gasoline at 2000 meters may be as high as 12 per cent and the rate increases with the altitude.

It is evident that a carbureter would be just so much better if it should maintain a constant carburetion under all circumstances. This is important from the point of view of efficiency and fuel consumption. An excess of gasoline is a useless expenditure which diminishes just so much the radius of the airplane and which may overheat the engine. An excess of air dilutes the mixture and lessens the power of the explosion.

Poor carburetion can, furthermore, cause fire. In this case there is usually an excess of air in the tubing, which facilitates the return of the flames to the carbureter.

Even with a perfectly adjusted carbureter, the consumption of gasoline varies greatly on different engines.

On some water-cooled engines it has dropped to about 200 grams (7 ounces) per horsepower-hour, but it should be noted that the most economical speed does not correspond exactly to the

maximum power, so that in practice this figure is brought something higher.

Ignition. — The explosion is caused at the right instant, on the inside of the cylinder, by an electric spark, due to the break current from a magneto. The electric circuit is made up as follows: An insulated wire connects the contact breaker to the spark plug. The latter is traversed by an electric conductor, which it insulates. The spark passes between the end of this conductor and a metal point, which is part of the mass of the engine, which in turn is connected to the negative pole of the magneto by an insulated wire.

Without entering into the details of the working of the magneto, it is enough to know that it can give either two or four sparks per revolution. It is controlled by a gear calculated according to the number of sparks and the number of cylinders to be supplied.

In the interest of efficiency, the ignition of the explosive mixture must take place at a definite position of the piston, shortly before it reaches the dead center, since there is a certain delay between the production of the current in the magneto and the explosion of the gaseous mixture in the cylinder.

The instant for producing the current is determined by the position of the moving parts of the engine, particularly of the piston itself. If the speed of the engine were constant, it would be enough to simply allow for the interval of time between the production of the current and the explosion, which always has the same duration. But the engine speed varies. If, for example, it increases, the piston will have passed the position it ought to occupy at the moment of explosion. Therefore the production of the spark must be regulated according to the speed of the engine.

At the moment of starting it is necessary to retard the spark, to avoid "back-firing," which is to say that, if the gas were exploded in advance of the dead center, the engine would turn in the wrong direction.

On certain engines the position of the spark is regulated by the pilot. On others it is automatic and works according to the speed.

Lubrication. — Lubrication is necessary whenever two pieces of metal rub against each other. If poorly lubricated, the parts heat, their surfaces become worn, they function poorly, and the parts are ruined.

Lubrication is accomplished in two ways:

1. By *dipping*. The part itself dips into the oil and also splashes the lubricant where it is needed. It is in this way that, in fixed engines, the crank case constitutes an "oil bath" for the crank and the lubrication of the cylinders is accomplished by splashing.

2. The oil is *forced* through tubes or holes bored in the parts to be lubricated. It then flows into a reservoir, from which it is returned by means of a pump. This method is becoming more and more general.

Oil is decomposed by heat. Consequently its consumption will be lessened in proportion to the cooling of the rubbing surfaces.

The weight of oil consumed by different engines varies greatly. From 50 grams ($1\frac{3}{4}$ ounces) per horsepower-hour for air-cooled engines, it can drop to one third of this weight for water-cooled engines.

In the case of rotary engines, where the carbureted air reaches the cylinders by passing through the crank case, castor oil must be used, which is not soluble in gasoline. This oil also has another advantage, that, being more viscous than mineral oil, it adheres better to the surfaces to be lubricated and is less removed by centrifugal force.

In fact, it is often used for fixed engines, although not necessarily.

Cooling. — Engines are cooled as in motor cars, either by water, or by air, or by both, water cooling being used more and more.

The cylinders of air-cooled engines are supplied with "fins," which increase their radiating surface and consequently the transmission of heat to the atmosphere. The rapidity of cooling may be still further increased by a fan. On rotary engines it is assisted by the motion of the cylinders themselves.

Water cooling becomes necessary when the dimensions of the cylinders exceed certain limits. The cylinders are surrounded by a jacket in which water circulates. From this jacket the water is conducted to a radiator, where it is cooled. It is drawn from the bottom of this radiator by a pump, which sends it back to the water jacket to repeat the process. Warm water being lighter than cold, it is arranged for the water to enter the jacket at the bottom and the radiator at the top.

The amount of water necessary for cooling is quite variable. For a 100-HP engine 15 to 20 liters (or quarts) of water is required. The radiator surface must vary according to the speed of

the airplane. For example, it must be from 6 to 8 square meters (65 to 85 square feet) for 100-HP engines. The rapidity of heat radiation is, in fact, proportional to the relative velocity of the air.

If the temperature of the water is never allowed to reach 100° C. (212° F.), there can be no boiling and consequently no loss of water.

Water cooling is more effective, permits a greater compression (whence a more efficient use of gasoline), and a smaller consumption of oil. Thus the additional weight of the water, radiator, and piping is more than compensated in long flights.

Measuring the Power of an Engine. — To measure the power of an engine it is necessary to know its couple (or torque) and the number of revolutions per unit of time. For this purpose various methods are employed.

1. The engine is mounted on a testing bed; that is, a platform free to oscillate is braked by a propeller, a "club" or a Froude brake. The engine couple is balanced by weights and the speed is taken by a revolution-counter.

2. Colonel Renard's tared airbrake enables us to determine the power developed by an engine on a fixed block. A piece of wood mounted

in place of the propeller carries two planes symmetrical in relation to the hub and which can be placed at varying distances from the shaft. Knowing this distance and the number of revolutions per minute, we can then get from a table the number of horsepower developed.

3. The engine drives the armature of a dynamo, whose field is free to oscillate. The couple is then measured by means of an arm with adjustable weights. This apparatus is called a dynamo-dynamometer.

Various Engine Types. — We recall that, in a one-cylinder engine, on the four-stroke cycle, only one of the strokes has a useful effect. Also in order that the engine couple may never be negative, 4 cylinders at least are necessary should their axes be parallel, as, for instance, in the case of an ordinary motor car, or at an angle of ninety degrees (*V*-engines). If the cylinders are arranged in a star, there must be at least five, since it can be demonstrated that their number must be odd in order to have the explosions equally spaced.

In the beginning of aviation we first sought to obtain lightness as the essential quality, and our attention was drawn to the radial type, the weight

of which is small, since it has a small crank and crank case. Then, in order to obtain better cooling of the cylinders, they were rotated, leaving the crank stationary. The rotary engine (Fig. 33) cools well, but, in spite of the care given to its manufacture and in spite of the good quality of the materials used, it remains a rather fragile

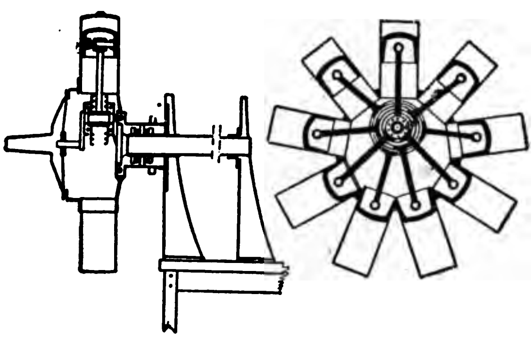

FIG. 33. Diagram of Rotary Engine

machine. The centrifugal force throws off the oil and exerts violent stresses on certain parts. The cylinders and especially the crank case must be made of steel. Up to the present time the power of these engines seems to be limited.

Now that prolonged flights and high power are required of airplanes, the lightness of an engine is no longer its dominant quality. Above all, it must be strong. This is a characteristic

of fixed engines, a little heavier than the rotary, but on the other hand, when cooled by water, consuming less oil and gasoline than the rotary engines.

The cylinders may be arranged in *radial*, in *V*, or in vertical *alignment*.

The *radial* engine usually has nine cylinders in the same plane, with one single crank pin. It

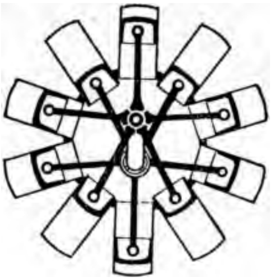

FIG. 34. Cross Section of a Fixed Engine, consisting of two Five-cylinder Groups

may also be composed of two five-cylinder groups, acting on two crank pins (Fig. 34).

On the one hand, this style of engine effects a slight saving in weight, due to the shortening of the crank, but, on the other hand, it offers a greater resistance to the air.

The *V*-engine consists of two groups of four or six parallel cylinders having the same crank. The

two groups are placed, as a rule, at such an angle that the explosions of the two sets of cylinders follow each other at regular intervals. In an eight-cylinder engine the two groups are set at an angle of 90° (Fig. 35). In a twelve-cylinder engine, the angle is not over 60°, sometimes only 45°.

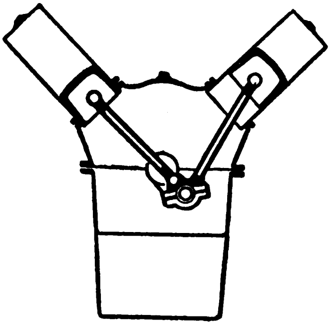

FIG. 35. Cross Section of an Eight-cylinder *V*-engine

The advantage of such an engine consists in having for eight cylinders, for example, a crank not much longer than for an engine with four vertical cylinders.

V-engines offer less resisting surface than radial engines, but are, however, more difficult to install in a narrow fuselage than the parallel-cylinder engines, derived from the customary motor-car engine.

The *vertical cylinder* engine offers the least resistance to the air, since the resisting surface is that of a single cylinder. Placed near the front of the machine, which is of advantage from the point of view of safety, it does not interfere too much with the view of the pilot.

CHAPTER IV

THE AIRPLANE IN FLIGHT

WHEN the propeller is set in motion, the airplane rolls along the ground. The pilot always starts facing the wind. In this way he more quickly attains the velocity in relation to the air, necessary for flight, while his speed in relation to the earth is diminished.

When the lift against the wings is equal to the weight of the machine, it leaves the earth. If the machine has an excess of power, it climbs, but it is limited in its climbing to a certain altitude. This is called the "height limit," or "ceiling," which depends upon the weight of the machine, the wing surface, and the engine power. Certain airplanes have exceeded 8000 meters (26,400 feet).

Why is there a maximum altitude? As the machine ascends the air becomes rarefied, and consequently the mass of each cylinderful diminishes. At 2500 meters (8250 feet) it is not over three fourths of what it was on the ground. The

engine which gave, for example, 100 HP can give, at this height, only 75 HP.

It thus arrives at the point where the machine becomes "sluggish," that is, where the engine furnishes just enough power to maintain horizontal flight. This is the height limit of the machine. It is determined simply by the rarefaction of the atmosphere, which diminishes the force of the engine.

This rarefaction also has an influence upon the lift of the wings, upon the pull of the propeller, and upon the passive resistance. In the complete calculations of an airplane design all these factors must be taken into account. But the resulting modifications practically offset each other and are of little importance in comparison with the diminishing power of the engine.

Thus the airplane can fly at any height between the ground and this height limit. We will consider it first under the supposition of calm and homogeneous air and then of disturbed air.

1. In horizontal, ascending, and descending flight.
2. In turning.
3. In starting and landing.

In passing we will note the faulty maneuvers that may cause a disturbance of the equilibrium.

Horizontal Flight. — The air is calm and homogeneous. The pilot has scarcely anything to do to preserve his lateral equilibrium. But the flight does not remain horizontal of itself. What are the necessary maneuvers for flying horizontally at a given altitude?

It is evidently necessary for the lift of the wings exactly to balance the weight of the machine. If

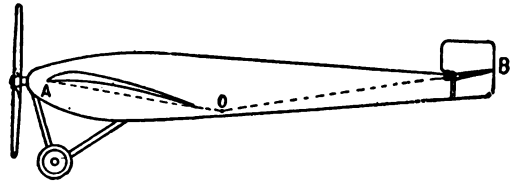

FIG. 36. Positive Longitudinal *V*. The angle *AOB* opens upward

the pilot has an excess of power at his disposal, there are two ways of maintaining horizontal flight. He can modify the speed of the airplane or the angle of incidence.

The speed of the engine is regulated by the admission of the explosive mixture by using the throttle. As for the incidence, we know that it is determined by the elevator.

When flying at a low altitude with an airplane that has a great excess of power, the machine will have a tendency to climb. To keep the flight horizontal, in spite of this, the elevator must be

lowered in order to diminish the incidence and consequently the lift.

A very simple calculation, verified by experiment, shows that the longitudinal equilibrium of a machine is stable, if the supporting surface and the elevator form an angle *AOB* opening upward (Fig. 36). This is called the positive longitudinal *V*. When the incidence of the elevator is greater than that of the wing, the angle *AOB* opens downward and *V* is said to be negative. The equilibrium is then unstable and the machine at the least provocation tends to roll over, which is more dangerous the nearer one is to the ground.

Therefore speed tests, with the throttle wide open, must be strictly forbidden on high-power machines at low altitudes.

If the elevator has a fixed part this must be carefully adjusted. Experiment has shown that the angle made by the lifting surfaces with this fixed part must not be less than 3°. If the pilot reduces this longitudinal angle, the tail of the airplane becomes more lifting, the total lift increases, and in this way a slightly more rapid ascent is perhaps obtained, but, on the other hand, the machine becomes more difficult to pilot, indeed, dangerous, so that this adjustment must be forbidden.

Ascending Flight. — We know that ascending flight is obtained by increasing the angle of attack by means of the elevator. The machine climbs, *not because the axis of the body is inclined, but because the increased incidence of the wings increases the lift.*

Calculation and experiment show that, for a given airplane, there exists a definite angle of attack which corresponds to the greatest excess of power. As it is just this excess of power that lifts the machine, the pilot must choose this angle of attack if he wishes to rise as swiftly as possible.

This "climbing angle of attack" is from 6° to 7° on present airplanes. It corresponds to a certain relative wind and consequently to a certain division of the speed indicator which the pilot determines experimentally. He must accordingly bring the speed indicator to this mark, in order to climb as fast as possible.

Descending Flight. — In descending, the weight adds its effect to the pull of the propeller. The latter must therefore be diminished by slowing down the engine. Otherwise, the lift of the wings increases with the speed of the airplane; the pilot must lower the elevator until V becomes negative; and there is danger of a nose dive, just as in horizontal flight at a low altitude.

Gliding. — When the propeller is stopped, or turns so slowly that it gives no pull, the airplane descends by gliding. If the motion is uniform, its equilibrium is very simple. The total lift of the air *R* is equal and directly opposed to the weight *W* (Fig. 37).

The pilot can to a certain extent lessen the pitch

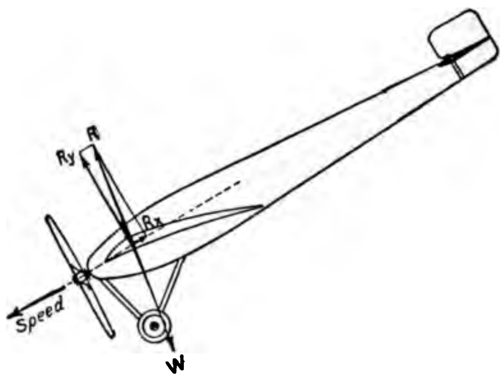

FIG. 37. Equilibrium in Gliding

of the descent. If the glide is necessitated by the stopping of the engine, it may be advantageous to reach the point as far as possible from the point where he happens to be; that is, to descend at the smallest possible pitch. This pitch then depends upon the "fineness" of the airplane, which has been already explained.

We can see on Figure 37 that the resultant *R* is directly opposed to the weight *W*, that is to

say, R is vertical. But we know that the angle of this resultant R with the perpendicular (Ry) to the direction of flight, is the least for a certain angle of attack, which is the optimum angle of flight. The pilot must, therefore, choose this angle of incidence in order to glide at the smallest pitch. In this case the inclination (stated in hundredths) of the resultant to the perpendicular to the trajectory measures the fineness of the airplane. On the best machines now made the fineness has been reduced to 0.12. For them the minimum gliding pitch is 12 per cent, or about one eighth. In other words a pilot commencing to glide at an altitude of one mile, for example, will land after having gone more than eight miles measured horizontally.

These figures have reference to still air. In case of wind the trajectory is modified by the drift.

The fineness of an airplane may be practically measured by its gliding trajectory, it being understood that the pilot chooses the most favorable angle of attack, which the speed indicator enables him to do.

Turning. — A body turning about an axis comes under the influence of a force directed toward the outside of the curve it describes. This centrif-

ugal force is proportional to the square of the velocity. It is just as much stronger as the radius of the curve is shorter.

In order not to side-slip, the airplane must dip toward the inside of the curve. The resultant R may then be resolved into two forces R_1 and R_2. R_2 counteracts the centrifugal force F, and R_1, which supports the airplane, must be equal to its weight W.

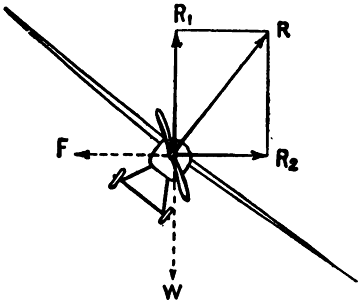

FIG. 38. Equilibrium in Turning. R, the reaction of the wings, counteracts W, weight of airplane, and F, the centrifugal force

It is evident, in Figure 38, that R_1 is smaller than R. Therefore, in order to turn horizontally, an increase of power is required, as much greater as the radius of the curve is smaller. Contrary to what takes place in other modes of locomotion, the velocity of an airplane must be increased in turning.

The inclination of the airplane is caused by the

difference in velocity of the two wings. In general the pilot does not need to make it. The wing on the outside of the curve travels a longer distance and therefore goes faster than the one on the inside, by reason of which it is subjected to a greater lift from the air and is raised. The inclination, once started, tends to increase. The pilot must limit it by using the wings flaps.

The shorter the turn the more the machine will be inclined, up to the limit where the wings become vertical and the elevator becomes the rudder, and vice versa.

It may be remarked that turning is a method of regaining one's equilibrium, as well as by means of the wing flaps. If an airplane dips to the left, for example, a turn to the right will bring it back to the horizontal position. This is called straightening up by foot.

Starting; Landing. — The maintenance of equilibrium in flight offers no great difficulties. Most pilots accomplish it easily. It is not the same in maneuvering near the ground, in starting to fly, and in landing.

While the machine is rolling along the ground it is exposed to shocks from the roughness of the field. It is, therefore, desirable to get off as soon as possible.

On the other hand, this must not take place before acquiring a sufficient velocity, without which the machine would simply point up, without rising, and side-slip. The speed indicator informs the pilot in this regard.

The landing must be made facing the wind, in order to lessen the velocity of the airplane in reference to the earth. It takes place, naturally, at the end of a descending flight, with slowed up propeller, or while gliding. When near the earth, the pilot flattens out the machine and flies at the lowest possible speed, that is, with quite a large incidence. The machine continues to descend and touches the ground.

The incidence must be increased when the speed is sufficiently reduced to prevent its rising again. On the other hand the pilot must not make this maneuver until the machine is quite near the ground; failing which the machine drops too suddenly and the landing gear may be broken.

Loss of Speed. — If there is danger while flying of the speed becoming too great, it must also not fall below a certain value, which may happen from two causes — either a too great slowing down of the engine, or an excessive angle of incidence on the part of the airplane. The controls, when the speed

is too slow, lose their efficacy. The machine no longer responds and slips sideways. At a great height the equilibrium may be regained. Sometimes pilots purposely let their machines fall "dead" and then dive in resuming flight. But if the loss of speed occurs near the ground, a fall is inevitable.

This certainty of accident is particularly to be feared in turning. We have seen that, in this case, the wings are less supporting than in rectilinear flight and that it is, therefore, necessary to increase the speed to maintain equilibrium. If there is no excess of power, it is not possible to turn horizontally, and still less in climbing.

Loss of speed in turning can be overcome if the airplane is up high enough. To regain speed it is necessary to follow a descending course, utilizing both elevator and rudder, whose functions overlap, in an inclined turning.

Thus, when the airplane performs a "tail spin," in spite of the pilot, he must dive, and instead of trying to avoid turning he must try to turn all the stronger. The machine descends, regains its speed, and becomes manageable.

Speed Indicator. — We see, from the preceding, how important it is that the relative speed of the

airplane to the air should be kept between certain limits. Some instrument for showing this relative speed at any instant is indispensable to the novice and of great value even to the most skillful pilot.

Speed indicators are of two kinds.

1. A small paddle, known as the *wind-paddle* speed indicator of Captain Etévé, is exposed to the relative wind. It can swing and is brought back by a spring. The motions of the paddle are indicated to the pilot by means of a pointer moving in front of a graduated scale.
2. The *Venturi Tube*, consisting of two cones joined by the top, and traversed by the relative wind. There is then produced, at the narrow portion of the tube, a *suction*, a function of the speed, which is transmitted to a manometer, water column, or aneroid barometer, facing the pilot.

This apparatus is of most service not only for avoiding nose dive or loss of speed, but assists in climbing most rapidly to a given attitude.

Air Disturbances. — The atmosphere is disturbed by two causes. Variations of pressure give birth to horizontal winds, and variations of temperature

to ascending and descending currents. Horizontal winds may themselves be changed into ascending or descending waves by the unevenness of the ground.

A uniform wind, whatever its direction, is not perceived on an airplane, no more than it is on a balloon. The machine is carried along, like a boat

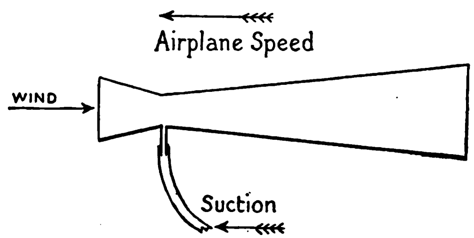

FIGURE 39. The Venturi Tube

crossing a stream. The pilot always has the sensation of a head wind, which depends upon the relative speed. The machine is therefore disturbed only by the *variations* in wind velocity, whether *horizontal* or *vertical*.

Horizontal variation of wind velocity. If it is a head wind parallel to the axis of the airplane, for example, a sudden increase in its velocity increases the lift on the wings, thus raising the machine during its continuance, without changing the inclination of the fuselage. Under these conditions its angle of incidence (Fig. 39) is reduced

from *α* to *β*, thus diminishing the lift and automatically restoring the equilibrium.

Reduction of wind velocity produces the opposite effect. The machine descends and its incidence increases until it becomes sufficient to support it.

If the gust *G* (Fig. 40) is not parallel to the path of the airplane, one wing will be struck before the other, causing a disturbance of the lateral equilib-

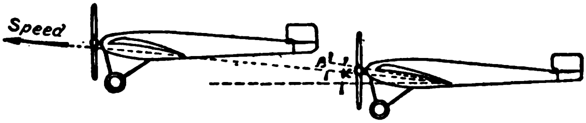

FIG. 40. *α*, Customary Angle of Incidence of Airplane. *β*, Angle of Incidence of Climbing Airplane

rium. The wing first struck is raised or lowered, according to whether the wind gust (G_1 or G_2) comes from the front or the rear, thereby increasing or diminishing the speed of the relative wind against this wing. At the same time the airplane, under the influence of its tail fin and rudder, tends to head around into the new wind, thereby beginning the turn *T*, which constitutes the second cause of lateral disturbance, but which may be in the opposite direction to the first (Fig. 41).

The pilot restores equilibrium by the usual means, wing flaps or rudder, and sometimes by both together.

Ascending and descending currents of air. These are due to two principal causes.

1. Air columns due to differences in temperature.

(*a*) Warm air, being lighter, rises. Ascending currents are noticed above radiating surfaces, such

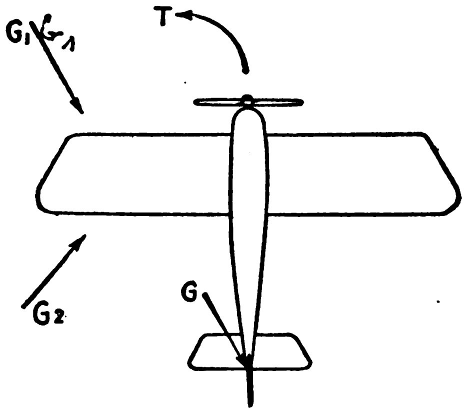

FIG. 41. Effect of a Lateral Gust *G*. Transverse Disturbance and Beginning of Turn *T*

as warm sand, chalk beds, etc. Their effect is just so much more noticeable as the heat is more intense and local. These heat eddies extend in summer to very high altitudes (several thousand feet) during the warmest part of the day, when the air is calm. A steady wind prevents their formation.

(*b*) Descending currents occur above cool dis-

tricts, valleys, and forests, which chill the air. The cold air becomes denser and causes a downward current from the layers above.

2. The wind follows the undulations of the earth. A shore cliff, for example, may cause an ascending wave, if struck by a wind coming from the water; or a descending wave, if the wind comes from the land.

Effects of vertical currents. The composition of these currents with the relative normal wind W

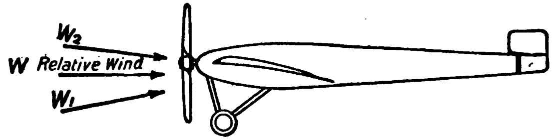

FIG. 42. W_1, Relative Wind changed by an Ascending Current. W_2 Relative Wind changed by a Descending Current

gives a wind W_1 or W_2. We see by Figure 41 that the ascending currents (W_1) have the effect of increasing the incidence, while the descending currents diminish it.

If the ascending current strikes the whole airplane, it is at first raised. As soon as this action is no longer felt, the airplane sinks. The contrary takes place in the case of a descending current.

The sensation of descending is much more noticeable than that of ascending: thus pilots are

much more impressed by a descending current, or on coming out of an ascending current. It is these two phenomena that have been given the descriptive but improper name of "airhole."

Vertical currents may affect only one part of the machine — one of the wings, for example — and thus disturb the lateral equilibrium.

Behavior of an Airplane in Flight. — The different maneuvers required to maintain equilibrium in quiet or disturbed air enable us to determine the conditions with which an airplane must comply, in order to fly well.

The controls must be energetic; that is, the rudder, elevator, and wing flaps must have a suitable form and sufficient surface, the latter depending, moreover, upon their distance from the center of gravity of the machine. The rudder must have certain well-defined dimensions, especially on a twin propeller airplane, in order to be able to keep the machine straight in case of the stopping of an engine or the breaking of a transmission gear. The present tendency on very swift machines is to construct all the control surfaces, rudders, and wing flaps in such a way that they will be "compensated." (See Vocabulary p. 114.)

Since an airplane flies under varying angles of incidence, all the passive parts may offer the least possible resistance, whatever may be the position of the machine. The body must be rounded as much as possible and the machine balanced in such a way as always to keep the *V* positive.

The forces acting upon an airplane are three.

1. The resultant of the forces exerted by the air upon the whole machine.
2. The pull or push of the propeller.
3. The weight of the airplane.

These three forces must counterbalance each other and thus their lines of action must be concurrent;—furthermore it is recognized to-day that their point of meeting must be a little (not more than a foot) below the center of gravity *G* (Fig. 43). It is evident that, on account of this device, if the propeller stops, the airplane will automatically begin to descend.

On a stable airplane, that is one with a positive longitudinal *V*, the center of thrust is displaced toward the rear, if the airplane tends to climb, and toward the front if it has a tendency to dive. This displacement tends to automatically reëstablish the longitudinal equilibrium, but this balancing effect or "automatic stability" must not be

too pronounced, for the machine would then follow every slight fluctuation of the wind and, in troubled air, would be constantly pitching.

To avoid this inconvenience, the tendency is becoming general to make the stabilizers non-supporting, which, as experience has shown, makes the airplanes more manageable and lessens the pitching and danger of a nose drive.

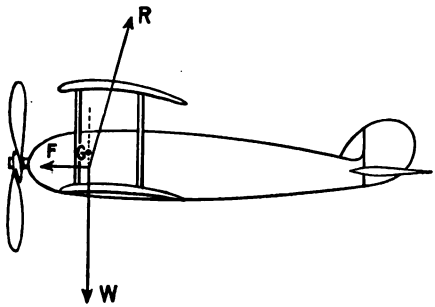

FIGURE 43. Equilibrium of forces on an airplane

Automatic Stabilizer. — The controls of an airplane are arranged in such a way that the movements of the pilot rapidly become reflex.

Nevertheless these movements may be too slow or not exactly proportioned to the intended effect. They sometimes require a fatiguing effort if the air is disturbed.

The delay comes from not perceiving at its start the phenomenon to be corrected. The airplanes

must already have an inclination sufficiently pronounced for the pilot to notice it.

On the other hand, the exact proportioning of the effort to the desired effect must evidently depend upon the skill of the pilot.

The automatic stabilizers which we have endeavored to produce have for their objects:

1. To save the strength of the pilot.
2. To start the reaction in the right direction as soon as the disturbing action begins.

The motions of the machine, thus counterbalanced from the moment of their inception, can be almost entirely suppressed.

Three means have been suggested for securing automatic stability.

1. *Hanging weights*, or levels which, when the machine tips, should keep a constant direction and (by means of an auxiliary motor) act upon the controls to restore the airplane to its normal position.

The hanging weights give counterindications, not only in turning, when they are subjected to centrifugal force, but also in horizontal changes of speed. An increase of speed throws them back-

ward, as if the machine were climbing, so that the different phenomena and those calling for opposite maneuvers give to the swinging weight the same motion. Thus, in spite of the ingenious efforts of Moreau, the hanging stabilizer has been abandoned.

2. The *wind paddle*, advocated by M. Doutre, which measures the relative speed of the machine and acts upon the elevator in order to keep this speed within certain limits.

The wind paddle gives correct indications of the relative speed and is therefore used as a speed indicator, but it gives no indication in regard to the transverse equilibrium. Moreover, wind devices have the disadvantage of following the continual variation of the wind, thus keeping the airplane continually pitching. The paddle should therefore be allowed to act upon the elevator only under certain well-defined conditions: It resists stalling on the one hand and nose diving on the other.

3. The *gyroscope*, which consists essentially of a rapidly revolving flywheel that establishes in space a definite plane, without regard to the position or changes of speed of the airplane, and thus maintains the longitudinal and lateral

equilibrium of the machine. Both theory and practice show that, if a gyroscope is suspended at a point of its axis situated a little above the center of gravity, this axis tends to pass through the center of the earth, making the plane of the flywheel horizontal.

On several occasions this method of stabilizing has been tried on ships and also on airplanes. Mr. Sperry succeeded in using it on airplanes in 1914. By means of two pairs of gyroscopes revolving in opposite directions, about axes at right angles to each other, he created a horizontal plane which was immovable in space. When the airplane tips, it moves in reference to this plane and makes electric contacts which effect the necessary maneuver by means of an auxiliary engine.

The wind paddle and the gyroscope, which, used separately, do not solve the problem, together produce encouraging results.

The stabilizer evidently cannot act for the pilot in landing. The stopping of the rudder and the righting of the airplane at the desired moment still devolves upon him, but his task is lightened by the fact that, during these maneuvers, he does not have to look out for the lateral equilibrium.

The stabilizer shows the pilot at any instant

the longitudinal and transverse inclination of the airplane. It is useful for flights by night, in fog, and in clouds. Furthermore it gives a reference plane for firing from an airplane.

Nevertheless, the increase in weight caused by it and the rapid maneuvers of aërial combat have stopped its use on military airplanes.

CHAPTER V

THE CHARACTERISTICS OF AN AIRPLANE

AN airplane may be characterized by its *speed*, the *useful load* it can carry, its *radius of action*, and the *maximum altitude* it can reach.

These different characteristics are related to each other according to certain mathematical principles, now known. Which is to say that if, on a given type of airplane, one of these characteristics is changed, the others must also be changed and the modifications thus introduced can be foreseen. Increasing one of the characteristics of an airplane always works to the detriment of another. I do not mean to say that we are confined within insurmountable limits. What is impossible to-day may be possible to-morrow, for into the relations, which connect the different characteristics to each other, enter three coefficients:

1. A factor which represents the solidity of the airplane and which depends upon the method of construction and materials employed.

2. The weight per horsepower of the power group and its hourly consumption of fuel. The propeller, and consequently its efficiency, is included in the power group.

3. The "fineness" of the machine.

It is manifest that these three coefficients are gradually changing. Airplane construction is being improved and airplanes are being made lighter so far as possible without sacrificing solidity. As regards the engines, the improvements are still more obvious. Their weight and fuel consumption have been greatly reduced and even their shape is better for installing in the fuselage. The fineness of the airplane has also been improved, both in the shape of the wings and of the passive parts.

When a constructor designs an airplane, he knows what engine is to be used and the kind of construction required. The fineness of his machine is, to a certain extent, the principal unknown factor. Nevertheless it is possible provisionally to establish these three coefficients, in order to design an airplane with a close approximation. The study of such a design would go beyond the limits of this little book, but we wish to call attention to a few important points.

1. Certain qualities directly opposed: horizontal speed and the possibility of climbing to a great height, for example.

If the wings of an airplane, whose height limit is 2000 meters (6600 feet), be slightly clipped, it will go a little faster (offering less resistance to the atmosphere), but it will not climb so high. By progressive diminutions of surface, we arrive at a very swift airplane, but one that can climb to only a very low altitude, like those built for the contests for the Gordon Bennett cup at Reims in 1913.

They made more than 200 kilometers (125 miles) per hour (which was a high speed for that time), but had a very low height limit, with no other load than the pilot and one hour's fuel supply. If they were on an elevation several hundred meters above sea level, they would not be able to leave the ground.

2. If certain conditions of speed, altitude, and load are required of an airplane, there exists an airplane with a maximum radius of action for *a certain engine power* which must not be exceeded.

In fact, the cell of an airplane is subject to the laws of the strength of materials, common to all kinds of construction.

When a cell is enlarged (like enlarging a photograph) it is known that the strength of each part is increased according to the *squares*, while the stress due to the weight increases as the *cubes* of the dimensions.

If, therefore, the same solidity is to be preserved, the weight of the machine must be increased more than the wing surface, in a complex ratio quite other than simple proportionality. We would, therefore, of necessity reach a point where the machine would be too heavy and would not be able to leave the ground.

Thus, starting with the light one-seater, which can carry no extra load, we come by successive gradations to a machine that is so heavy that it can no longer carry any load. Between these two extremes the magnitude of the useful load constantly varies. There is, accordingly, a type of airplane which, equipped with a certain engine, can carry a heavier load than any of the others. An airplane, of the same family, if fitted with a more powerful engine, other things being equal, would have a smaller lifting power.

VOCABULARY OF AVIATION TERMS

Aileron. — See *Wing Flaps.*

Air Dynamics. — The science which treats of air in motion, its velocity, its pressure, and its action upon bodies of different form and character.

Anemometer. — Instrument for measuring the velocity of the wind at any point.

Angle of Attack, Attacking Angle. — Angle between the direction of the relative wind and the cord of a lifting surface.

Angle of Incidence. — See *Angle of Attack.*

Aspect Ratio. — See *Elongation Ratio.*

Attacking Edge. — See *Leading Edge.*

Automatic Stabilizer. — Apparatus designed to take the place of the pilot in maintaining the equilibrium of an airplane.

Axis. — Imaginary line about which anything turns.

Balancing Flaps. — See *Wing Flaps.*

Barometric Pressure. — Pressure of the atmosphere, as shown by the barometer. The normal pressure at sea level is 760 millimeters of mercury, or 1033 grams per square centimeter, or about 15 pounds per square inch.

Body. — That part of an airplane which is occupied by the crew, engine, tanks, etc., and to which the wings, landing gear, and other organs are attached. A long body is often called "fuselage" and a short body, "nacelle."

Braced Girder. — Structure formed by stringers, cross-bars, and wire stays — as for example the frame of a wing.

Cabane. — A French word to denote the mast structure, projecting above or below the body of a monoplane, to which the load wires are attached.

VOCABULARY OF AVIATION TERMS

Ceiling. — See *Height Limit.*

Cell. — That portion of a biplane comprising the wings and their supporting spars, ribs, struts, and stays.

Center of Gravity. — The weight of a body may be considered as existing in a single point, called the *center of gravity*, about which the body will balance in whatever position it is placed.

Centrifugal Force. — The force exerted away from the center by a body moving in a circle. This force is directly proportional to the mass of the body and the square of its velocity, and inversely proportional to the radius of the circle.

Cockpit. — That portion of the body of an airplane that is occupied by the pilot.

Compensate. — To balance steering surfaces (rudders and wing flaps) by extending them past their axes, so as to render their control easier.

Couple. — Two equal and opposite parallel forces tending to produce rotary motion.

Depth. — The measurement from front to back of airplane parts, especially of the wings.

Drag (French, *trainée*). — The resistance offered by an airplane to its forward motion through the air. It must not be confused with *drift.*

Drift (French, *dérive*). — Sidewise motion due to lateral wind. The angle made by the axis of an airplane, affected by a lateral wind, with the course followed in reference to the ground. Care should be taken not to confuse this with *drag.*

Efficiency. — The efficiency of a machine is the ratio of the energy it puts forth to that which it receives.

Elevator. — A hinged surface at the rear of an airplane, oscillating about a horizontal transverse axis, for controlling the angle of incidence or longitudinal attitude of the airplane.

Elongation Ratio. — (1) *Surfaces,* ratio of span to depth. (2) *Fusiform bodies,* ratio of total length to greatest transverse dimension.

Entering Edge. — See *Leading Edge.*

Fin. — See *Stabilizing Plane*.

Fineness of an Airplane. — The ratio of the drag to the lift for the optimum angle of attack.

Fuselage. — See *Body*.

Get Off (French, *décoller*). — An airplane "gets off" when it leaves the ground, after running a certain distance.

Gliding. — A machine glides when the propeller has stopped or is exerting no force.

Graphic. — A curve, plotted by means of coördinates (forming squares), showing the relation between two sets of phenomena.

Gyroscope. — See page 105 of the text.

Head Resistance. — See *Drag*.

Height Limit. — The highest altitude at which a given airplane can maintain horizontal flight.

Horsepower (HP). — Unit of power, equal to 550 foot-pounds or 75 kilogrammeters per second.

Incidence. — See *Angle of Attack*.

Inclinometer. — Instrument for determining the inclination of an airplane to the horizontal.

Landing Chassis. — See *Landing Gear*.

Landing Gear. — The under structure of an aircraft designed to carry the load when resting or running on the ground.

Leading Edge. — The front edge of a wing.

Lift. — The vertical or lifting component of the force exerted by the relative wind upon the wings or other parts of an airplane. It is exactly opposite in direction to the action of gravity and, for an airplane flying *horizontally*, is just equal to the weight of the machine. It should not be confused with the *thrust*, although it is a *component* of the latter.

Load per Horsepower. — Quotient of the total weight of an airplane divided by the horsepower of the engine.

Load per Square Foot. — Quotient of the total weight of an airplane divided by the number of square feet of wing surface.

Longitudinal *V*. — The dihedral angle made by the elevator with the mean plane of the supporting surfaces.

Loss of Speed. — Condition existing when the relative speed of an airplane falls below that necessary for its proper control.

Manometer. — Instrument for measuring elastic pressure, as of gases.

Nacelle. — See *Body*.

Nose Dive. — A dangerously steep descent. An airplane makes a nose dive when its path approaches nearer and nearer to the vertical in spite of the pilot. This proceeds: (1) From the faulty design of certain machines; (2) In the case of a well-designed machine, from flying with too much power. The airplane can then be righted if it is at a sufficiently high altitude.

Optimum Angle. — The angle of attack for which the ratio of the drag to the lift has the smallest value.

Passive Elements. — All the parts of an airplane that offer resistance to its forward motion, without contributing to its support.

Pitch. — To plunge in the fore and aft direction.

Pitch of a Propeller. — The distance forward that a propeller would travel in one complete revolution.

Power. — The amount of work that a source of energy can do in one second (see *Horsepower*).

Power Group, Power Plant. — The engine and propeller and accessory parts.

Pressure Diagram of a Surface. — Combination of two curves showing the distribution of pressure along a section perpendicular to the leading edge.

Pusher. — A rear propeller, or a type of airplane with the propeller or propellers back of the wings.

Propeller Thrust. — The total force exerted by the propeller upon an airplane. This force is opposed to the head resistance or drag and causes the airplane to move forward against the relative wind.

Relative Wind. — The apparent motion of the air relative to an airplane or other moving object.

Renard Fan Dynamometer. — Apparatus for testing the power of an engine by measuring the resistance of the air against paddles.

Ribs. — Light wood strips which connect the spars and support the canvas covering of the wings.

Rudder. — A hinged or pivoted surface, at the rear of an airplane, oscillating about a vertical axis, by means of which the airplane is turned to the right or left.

Rudder Bar. — The foot-bar by means of which the rudder of an airplane is worked.

Seaplane. — An airplane which can alight and float on water and can arise from it.

Servo-Motor. — An auxiliary source of energy employed for any purpose, and especially in operating the controls of an airplane by a simple contact, made either by the pilot or an automatic stabilizer.

Side Slip. — Caused by loss of speed or stalling of the engine. The machine dips, cannot right itself, and slips sidewise.

Span. — The extreme width of an airplane. The distance from tip to tip of a pair of wings.

Spar. — A long piece of wood or other material. Either of the transverse beams of an airplane, forming the main supports of the wing surfaces, to which are attached the ribs, struts, and stays.

Spread. — See *Span.*

Stabilizing Plane. — Any fixed plane, placed at the rear of an airplane, to promote stability. When vertical, such a plane is called a fin or tail fin; when horizontal, it is called a stabilizer.

Stalling. — See *Loss of Speed.*

Static Tests. — Experiments to test the strength of an airplane by weighting the wings with varying loads of sand.

Statoscope. — Instrument to indicate to the pilot whether the aircraft is ascending or descending.

Stay. — A metal wire or cable for bracing the framework of an airplane.

Stream Lines. — Easy curves from front to rear of the body, struts, and other parts of an aircraft, to avoid eddying of the air and to minimize the head resistance.

Strut. — Upright member of an airplane cell resisting compression in the direction of its length.

Sustainer. — See *Cell.*

Tail Fin. — See *Stabilizing Plane.*

Tangent. — An airplane is "tangent" to a certain altitude, which it can maintain in horizontal flight, but which it has not the power to surpass (see *Height Limit*).

Thrust. — See *Propeller Thrust.*

Torque. — See *Couple.*

Tractor. — A front propeller, or a type of airplane with the propeller or propellers in front of the wings.

Trailing Edge. — Rear edge of a wing.

Trajectory. — The path of an airplane or other object through the air.

Transverse *V*. — The dihedral angle formed by the mean planes of the right and left wings.

Warping. — The control of the lateral equilibrium of an airplane by changing the incidence or curvature of the wings. The same result is obtained by the play of the wing flaps.

Wings. — Supporting surfaces of an airplane, distinction being made between the lower and upper face or back.

Wing Flaps. — Movable surfaces forming the rear and outer part of the wings. The two flaps are symmetrical and oscillate in opposite directions to each other, about an axis parallel to the leading edge. They thus change the relative *lift* of the two wings.

Wing Spar. — See *Spar.*

Work. — See page 50 of text.